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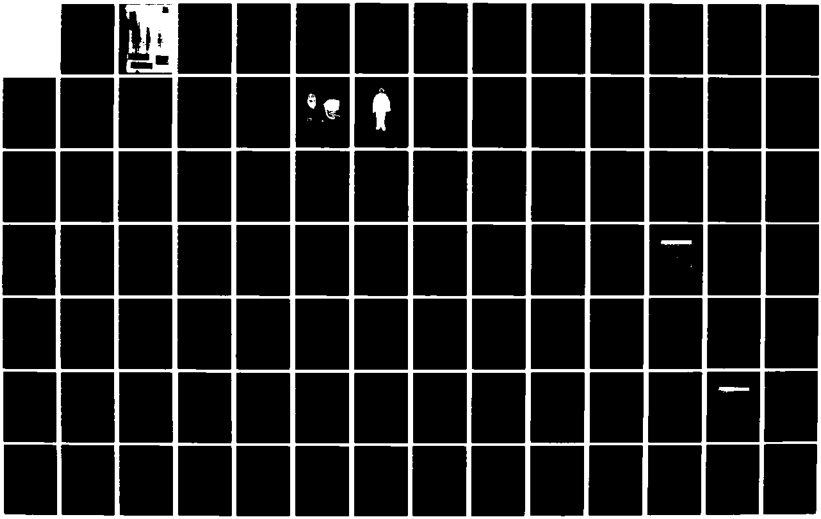

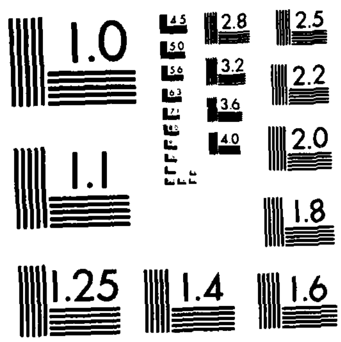

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Report evaluates the current US Army chemical overgarment in the MOPP-4 configuration under various environmental conditions. The effect of humidity and water loss is discussed in detail. It was found that the current safety guidelines as presented in FM 21-40 are inadequate. An effective temperature vs. tolerance time graph is developed for continuous wear. The graph is also developed for use with the BOTSBALL thermometer. A safety limit for the amount of water that can be lost is presented.

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Analytical Evaluation of Current United States Army Guidelines for Soldiers Wearing NBC Protective Overgarments Under Various Environmental Conditions

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Final report 26 April 1985

A thesis (report) submitted to the University of Texas at Austin, Texas, in partial fulfillment of the requirements for the degree of Master of Science in Engineering.

ANALYTICAL EVALUATION OF CURRENT UNITED STATES ARMY

GUIDELINES FOR SOLDIERS WEARING NBC PROTECTIVE

OVERGARMENTS UNDER VARIOUS ENVIRONMENTAL

CONDITIONS

APPROVED:

To my wife, Becky, without whom I would not be complete.

"Therefore shall a man leave his father and mother,

and shall cleave unto his wife:

and they shall become one flesh."

Genesis 2:24

ANALYTICAL EVALUATION OF CURRENT UNITED STATES ARMY GUIDELINES FOR SOLDIERS WEARING NBC PROTECTIVE OVERGARMENTS UNDER VARIOUS ENVIRONMENTAL CONDITIONS

BY

LARRY TIM RICH, B.S.

REPORT

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE IN ENGINEERING

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May, 1985

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Larry Tim Rich

The University of Texas at Austin
May, 1985

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1.5 Solutions to the Problem

1.5.1 Cooling Suits

One solution to alleviating heat stress is to cool the soldier's body. Billingham [12] first recommended a suit with cooling tubes, and a prototype was constructed in 1963 by the Royal Aircraft Establishment. Research on this suit (and its successors) resulted in the development of liquid-cooled garments (LCG's) for use by NASA in the APOLLO program [13]. The major problems with LCG's in the Army's case are their size, weight, cost, and maintenance.

1.5.2 Cooling Vests

The next development was the cooling of specific areas of the body. Areas studied include the head [14] and the torso [15, 16]. Researchers found that cooling the torso region limited temperature increases in major organs owing to cooling of blood as it passed through the skin [17]. It has been shown that liquid-cooled vests (LCV's) can sufficiently reduce thermal stress and control body dehydration [15]. The three major types of LCV's in use today are:

1. Ambient Air (AA) - This LCV circulates ambient air through the vest.
2. Conditioned Air (CA) - This LCV cools and dries ambient air before sending it through the vest.
3. Cooled Liquid (CL) - This vest circulates chilled water through the vest to cool the soldier.

loss, the soldier's temperature will rise and he will eventually become a heat casualty [10]. Third, if the soldier loses too much body fluid without replenishment, he will dehydrate and become a casualty [11]. All three problems deal with the removal of heat from the soldier. The problem can be viewed, therefore, in terms of heat removal versus chemical protection, as shown in Figure 1-3.

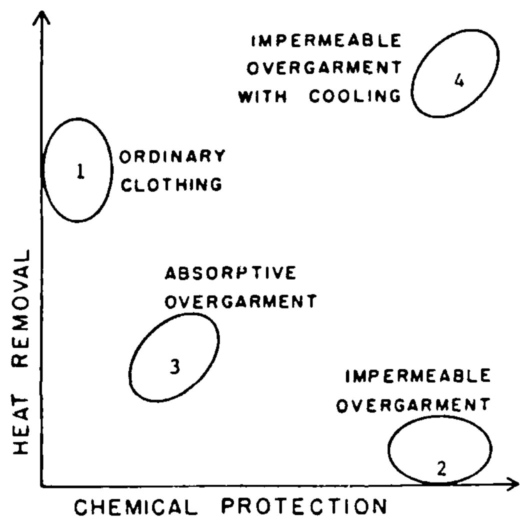

Figure 1-3: Trade-off Between Heat Removal and Chemical Protection [9]

As can be seen from Figure 1-3, there is a trade-off. The current Chemical Defense Protective Overgarment (Circle 3) is a compromise between the battle fatigue uniform (Circle 1) and the completely impermeable Toxilogical Agent, Protection uniform (Circle 2). Obviously, the ideal suit would allow both high heat removal along with a high degree of protection (Circle 4). Unfortunately, there is no suit presently available that can do both.

Table 1-2: Enemy Situation and Appropriate MOPP Level [8]

MOPP Level	Enemy Situation
0	Use of Chemical Warfare weapons has not yet occured. Also used when units are first deployed to a theater of operation.
I	Use of Chemical Warfare weapons probable or likely.
II	Use of Chemical Warfare weapons iminent. Use of weapons in other areas may have already occured.
III	Unit is receiving incoming artillery, OR non-persistent chemical agents have been encountered.
IV	Persistent chemical agents have been encountered.

garment must withstand penetration by liquid agents for up to six hours, it is semi-impermeable and, therefore, does not 'breathe well' [7]. This results in retention of heated air next to the soldier and increases the heat load on the soldier. If there is no mechanism by which the soldier can lose as much heat as he produces, his body temperature will rise, resulting in sweating. The Chemical Defense Protective Overgarment limits the amount of sweat that can be evaporated through the garment, thereby reducing the evaporative cooling effect. If the sweating is not limited, three things will occur. First, the garment's protective capability will be degraded since the charcoal lining will absorb the sweat and lose its ability to absorb liquid agents [9]. Second, without the ability to equalize heat production and

Table 1-1: Mission Oriented Protective Posture Levels [8]

MOPP Level	Equipment Worn/Carried
0	Mask carried. Chemical Defense Protective Overgarment, gloves, and overboots readily available.
I	Chemical Defense Protective Overgarment, worn open or closed. Mask, gloves, and overboots carried.
II	Chemical Defense Protective Overgarment, worn open or closed. Overboots worn. Mask and gloves carried.
III	Chemical Defense Protective Overgarment, worn closed. Overboots and mask worn. Hood made be rolled up or down. Gloves carried.
IV	Chemical Defense Protective Overgarment, worn closed. Overboots, gloves, and mask worn. Hood worn rolled down.

NOTE: In MOPP II & III only the overgarment coat may be worn open. The trousers are worn closed.

1.4 Problem Area

Thus, the major problem facing the commander is not what MOPP level to put his troops into, but rather how long his troops can remain in that MOPP level and still accomplish the unit's mission. In hot weather, when the soldier assumes MOPP-IV, he is totally encapsulated. This posture seriously hinders the body's natural efforts to regulate temperature through heat loss via evaporation of sweat. Since the

attack in order to survive. A fourth manual (FM 3-100) gives overall guidance for operations during chemical warfare.

Part of the Army's doctrine is to protect the troops at a level which will still allow the mission of the unit to be accomplished. The policy that the United States Army has developed is based on a five-level system, known as the Mission Oriented Protective Posture (MOPP) levels. The five MOPP levels, as of 1 January 1985, are shown in Table 1-1, on page 9.

The Mission Oriented Protective Posture levels were designed to allow commanders to pick the level that would give their troops sufficient protection against the current threat while still allowing commanders to accomplish the mission. The MOPP levels and the common threat situation that that level would be used for are shown in Table 1-2, on page 10.

As can be seen from Table 1-2, the commander can assess the current situation and then choose the MOPP level which will allow his unit to accomplish its mission while providing protection for the troops. While use of the MOPP levels should reduce the number of casualties the unit receives due to chemical agents, the commander must currently trade protection for work output due to the heat build-up that soldiers experience while in MOPP-IV.

Biological Warfare agents in order to develop defensive measures that will protect our soldiers.

In accordance with this, the United States Army has develcped its own doctrine for how the Army will fight in a Nuclear, Biological, and Chemical environment. Since we are obligated by the Protocol to refrain from first-use, Army doctrine emphsizes defensive actions and procedures [2]. This results in having to develop procedures for fighting, and winning, in a chemical environment. The major part of the Army's doctrine for chemical warfare is presented in three unclassified documents:

1. FM 100-5. Operations. This manual contains the general philosophy of how the Army is to conduct itself in war.
2. FM 21-40. Nuclear, Biological, and Chemical Defense. This is the basic guide for unit commanders on how to survive and fight in a Nuclear, Biological, and Chemical environment.
3. FM 3-87. Nuclear, Biological, and Chemical Reconnaissance and Decontamination Operations. This manual is the basic guide for commanders of chemical units on how to perform their mission in a Nuclear, Biological, and Chemical environment.

It should be noted that these three documents will be replaced over the next two years by a new series of manuals. The new manuals break the Army's doctrine for chemical warfare into three areas: contamination avoidance (FM 3-3), protection (FM 3-4), and decontamination (FM 3-5). FM 3-4 (Final Draft), NBC Protection, outlines the procedures to be used before, during, and after a chemical

The Chemical Defense Protective Overgarment is made of a nylon fabric material, lined on the inside with a charcoal-impregnated polyurethane foam bonded to a nylon tricot fabric [6]. The protective covering absorbs chemical agents that come in contact with the garment. The garment is designed to withstand penetration by liquid chemical agents for up to six hours [7]. In addition to the Chemical Defense Protective Overgarment, the soldier wears butyl-rubber overboots and gloves. The overboots are of a one-size-fits-all design, and the gloves are made of a thinner rubber in order to provide better manual dexterity while wearing the gloves. Cotton glove inserts are also provided to absorb sweat [6]. These three pieces of equipment comprise the major protection, along with the hood, from persistent chemical agents. See Figure 1-2, page 5 for a picture of the Chemical Defense Protective Overgarment and overboots.

1.3 Current Army Doctrine

Since 1969, when the United States Senate ratified the Geneva Protocol of 1925 which deals with the use of asphyxiating gases in war, the country's policy towards chemical warfare has been [2]:

1. We will not use Chemical Warfare weapons first.
2. We will never use Biological Warfare weapons.
3. We reserve the right to keep stockpiles of Chemical Warfare agents on hand for use in 'retaliation-in-kind' strikes if Chemical Warfare weapons are first used against US troops.
4. We reserve the right to continue testing both Chemical and

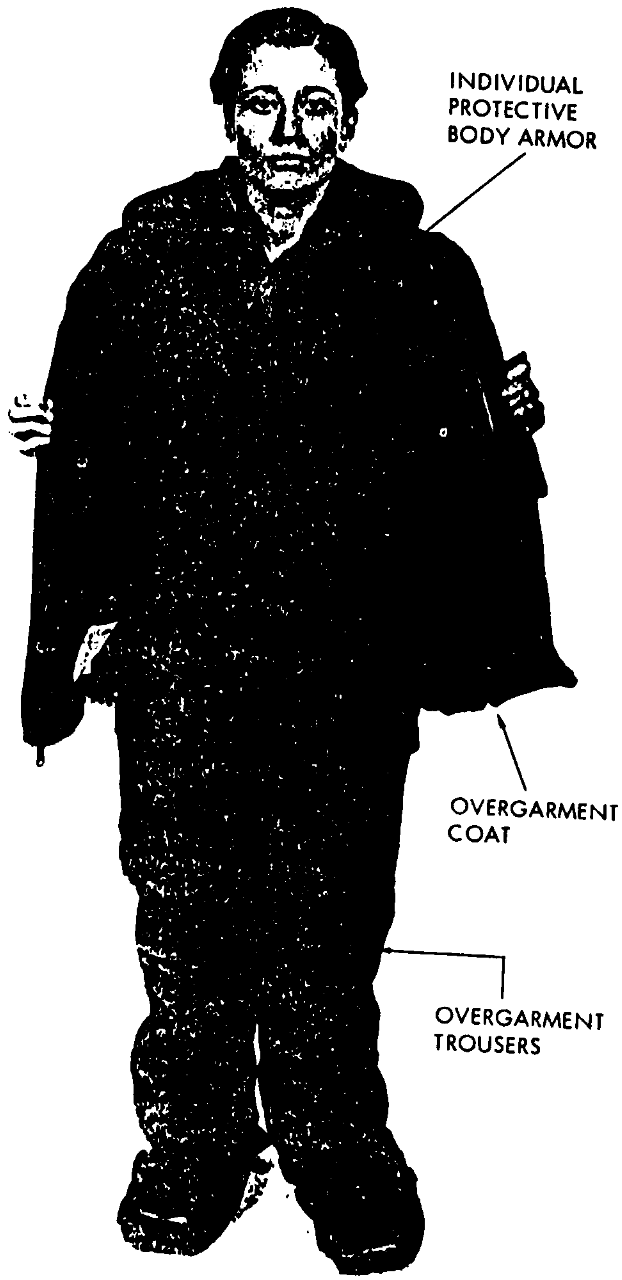

Figure 1-2: Chemical Defense Protective Overgarment [6]

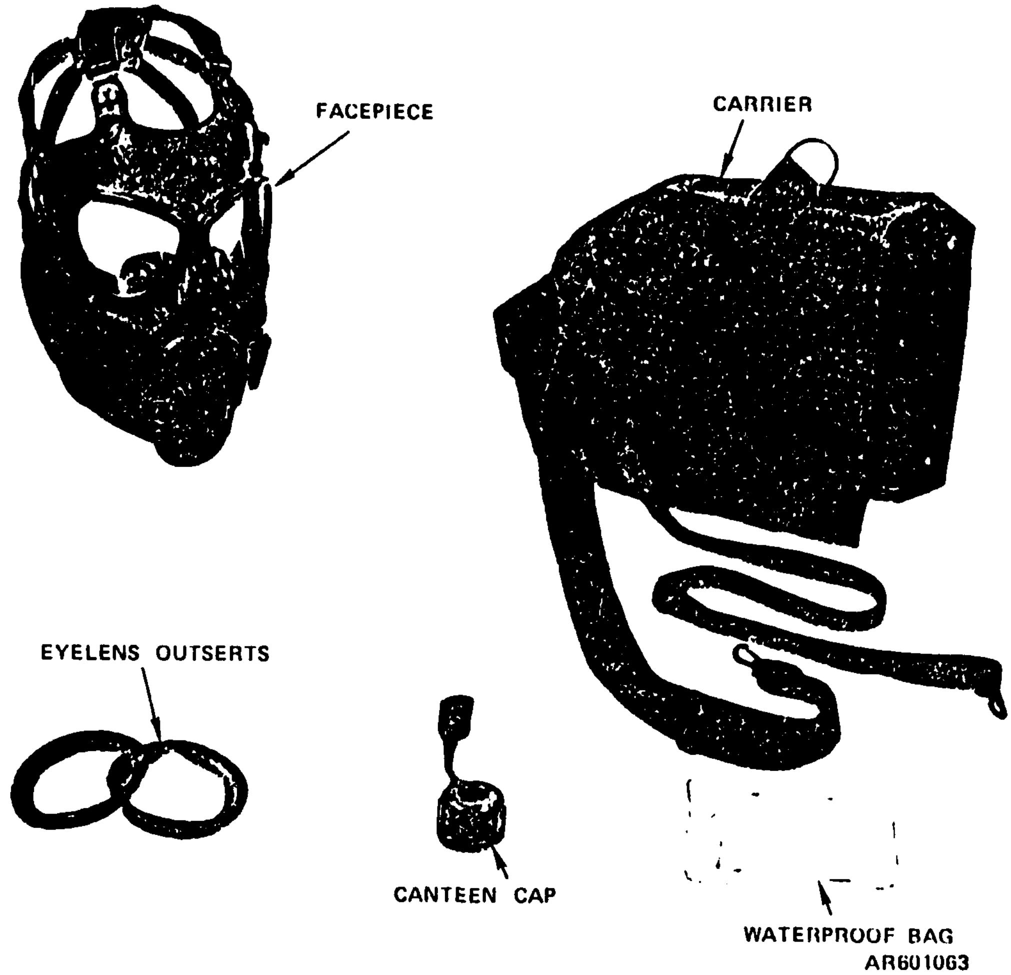

Figure 1-1: M-17/M17A2 Protective Mask [4]

1.2 Current Chemical Defense Equipment

The current Chemical Defense Equipment provided to the individual soldier consists of the following pieces of equipment:

1. Chemical Defense Protective Overgarment (CDPO). This is a two-piece suit that is worn over the regular battle fatigue uniform and individual body armor. The Battle Dress Overgarment (BDO), which will replace the CDPO, is in its final stages of development prior to being fielded.

2. Protective Mask. The type of mask issued is based upon the duties that the soldier is required to perform. For most soldiers, they will be issued either the M17/M17A2 or the M25/M25A1 masks. Aviators are issued the M24 mask.

3. Chemical Protective Glove Set and Footwear Covers (Overboots). Issued one pair each.

4. Decontamination and First-Aid Kits. Each soldier is given an M258A1 Skin Decontamination Kit, an M13 Decontamination Kit (to use on individual equipment), three Nerve Agent Antidote Kits (NAAK), Mark I, which contain three atropine and three oxime Autoinjectors for counteracting nerve agent poisoning, and a container of Amyl Nitrite ampules to be used for blood agent poisoning.

This equipment is designed to protect the individual soldier from field concentrations of chemical agents. The protective mask is maded of butyl rubber and completely covers the front of the head [4]. Refer to Figure 1-1, page 4, for a picture of the M17/M17A2 mask. The hood, made of butyl-rubber-coated nylon cloth, is worn over the mask in order to provide protection from vapor agents and liquid droplets [5]. This is accomplished by using the soldier's expired air to develop an overpressure inside the hood, which keeps non-persistent agents from reaching the neck and head area.

of chemical agents being used is present. One out of every three rounds for cannon artillery currently stockpiled in eastern Europe is filled with chemical agents. And, unlike the United States, the Soviet Union has not ruled out the first use of chemical agents [2]. In fact, the Soviets consider chemical agents as merely weapons of mass destruction, and delegate the authority to initiate their use dow-- to the Front commanders. See Appendix A for a more detailed discussion of the Soviet concept for employment of chemical agents in their offensive doctrine.

Recent events, though, have shown that the United States Army also must be concerned with an enemy's use of chemical agents elsewhere in the world. In Afghanistan, the Soviet Union is using chemical agents against the rebel fighters. In Cambodia, the Vietnamese are using chemical agents (Yellow Rain) against the mountain tribes [3]. North Korea maintains a stockpile of chemical weapons, and frequently conducts training exercises that include the use of diluted chemical agents. Cuba maintains a small stockpile that can be shipped to Central America. And any country that has a chemical processing industry, especially one that produces insecticides, has the capability of mass producing chemical agents in a relatively short period of time. Clearly, in every part of the world where we confront a Soviet ally, we are faced with the threat of chemical agents. Thus, the United States Army must be ready to fight and win a war in a chemical environment anywhere in the world.

Chapter 1

Introduction

Throughout the history of man, warriors have fought in various climates that imposed differing thermal stresses to those men. Both heat and cold stress are a function of the meteorlogical conditions, as well as the clothing worn by the soldier and the equipment that he uses. Since World War I, when chemical warfare was first used on a massive scale, the thermal stress imposed on soldiers during hot weather, while wearing protective clothing, has become a major concern [1]. In the years since World War I, the lethality of the chemical agents has increased, requiring that protective clothing become more impermeable. This results in greater heat stress for the soldier.

1.1 Threat Capabilities

At the present time, the Soviet Union and its allies are considered to be the United States' major threats. For many years the concern was centered in Europe, and the major emphasis of the United States Army was on the North Atlantic Treaty Organization (NATO) area. Indeed, the Soviet Block threat in Europe is real, and the possibility

Tests have been conducted by the United States Army to determine the best LCV for meeting the needs of the Army [18]. Ambient Air LCV's (AA LCV's) were found to provide inadequate cooling power [19]. Conditioned Air LCV's (CA LCV's) were chosen over Conditioned Liquid LCV's (CL LCV's) for all Army aircraft and most ground vehicles [20, 21]. The deciding factor was not the cooling power, since the CL LCV proved to be the most efficient, but rather troop safety. If the CL LCV were to fail while in use, then the soldier's overgarment would absorb the cooling liquid and lose some of its protective capability. The CA LCV presents no such safety problem.

The primary candidate for the dismounted Infantryman in terms of LCV's is a CL LCV with a Sterling engine [9]. This system was initially chosen due to its capability for handling all climatic conditions, its light weight, and its relatively low maintenance costs. However, the CL LCV still has the safety problem that was noted in the previous paragraph, and the dismounted soldier has more risk of tearing the tubing on his LCV than a mounted soldier. Therefore, the United States Army is not completely committed to having LCV's for the dismounted Infantry. The Army is also beginning to move toward more "light" divisions in order to increase the number of divisions that can be moved at one time by the Military Airlift Command (MAC). This means more, not less, dismounted Infantry. Thus, the problem of the dismounted Infantry is more critical now than it was a few years ago. Finally, regardless of whether the Army approves an LCV for the dismounted Infantry or not,

it would be the late 1980's or early 1990's before a LCV could be fielded in mass. Therefore, heat stress problems for the Infantryman who does not have an LCV must be addressed.

1.6 Immediate Solution

While LCV's could provide both near- and far-term solutions, their fielding is still several years away. Therefore, guidelines that commanders may use now with equipment currently in the field must be developed in detail. Currently, FM 21-40 contains guidelines for commanders to follow. In addition to the Mission Oriented Protective Posture levels previously cited, there are two additional tables that deal with heat stress. The first is a table containing maximum allowable work times for soldiers who perform continuous work at various levels in various temperature ranges and MOPP levels. The second table is a work/rest cycle table with recommended work/rest cycles for different MOPP levels at different work levels for several temperature ranges. See Figures 3-2 and 4-27, on page 38 and page 67, respectively, for additional details about the tables [22]. These tables, however, are of questionable value today since the MOPP levels on which these tables were based do not correspond to the current MOPP levels cited in Table 1-1, on page 9. Also, the tables use only work level, temperature, and MOPP level as variables. To view hot environments as being defined by temperature alone is rather simplistic. The Federal Standards [11] call for the use of temperature, humidity, radiation, and

windspeed in a combined index known as the Wet-Bulb Globe Temperature (WBGT).

1.7 Scope of Report

This report is concerned with the immediate problem of thermal stress experienced by soldiers while wearing MOPP-IV, in a hot environment. Specifically, three items of interest will be investigated. First, this report will validate and subsequently use a computer model of the human thermal system to develop a continuous work table using a modified WBGT index. Second, the cyclic work/rest values given in Table 5-2 of FM 21-40 will be checked using the computer model. Third, fluid loss via sweat production will be predicted for both continuous work and cyclic work, and possible safety implications will be discussed. FM 21-40 was used in lieu of FM 3-4 (Final Draft) since FM 3-4 does not contain tables for continuous work or work/rest cycles. FM 3-4 does provide extensive tables, by type of unit, which allow one to estimate the degradation effect of MOPP-IV on times required to perform unit missions at various temperatures. However, these tables provide no data as to whether the times listed take into account work/rest cycles, or whether they are for continuous work. Also, there is no assurance that use of the times listed will prevent heat casualties. Thus, the tables from FM 21-40 were used.

Chapter Two covers the theories underlying thermal stress and

the responses of the human body; the use of environmental conditions to predict thermal stress; and development of a possible standard for use in terms of amount of water lost from the body. Chapter Three describes the computer model used and covers the process of validation of the model. Chapter Four presents results computed using the model to analyze continuous work, as well as the cyclic work and sweat production. Chapter Five presents the conclusions of this report along with areas for further research.

Chapter 2

Theory

2.1 Thermal Energy Balance

The human body is capable of regulating the amount of heat it gives up or stores through a complex system. This function can be modeled in terms of the different ways the body can produce, lose, or gain heat. The steady-state thermal balance may be written as:

$$M \pm Q_{cond} \pm Q_{conv} \pm Q_{rad} - Res - Diff - Evap = 0 \qquad (2.1)$$

where:

M = Metabolic Heat Production (Net).

Q_{cond} = Environmental Conductive Heat gain/loss to the body.

Q_{conv} = Environmental Convective Heat gain/loss to the body.

Q_{rad} = Environmental Radiative Heat gain/loss to the body.

Res = Heat loss via the respiratory tract; sensible and evaporative.

Diff = Heat loss via diffusion of water to the skin.

Evap = Heat loss via evaporation of sweat.

When there is an imbalance in equation (2.1), a heat storage term (S) must be added to the equation, giving:

$$M \pm Q_{cond} \pm Q_{conv} \pm Q_{rad} - Res - Diff - Evap = \pm S \qquad (2.2)$$

where:

+S = Heat stored in the body.

-S = Heat taken from the body.

In hot environments, the conductive heat term (Q_{cond}) is usually negligible due to the small area of contact between external objects and the skin. Also, the effect of the respiratory heat loss is neglected when a soldier is in MOPP-IV, and, therefore, the respiratory term (Res) may be dropped. This reduces equation (2.2) to:

$$M \pm Q_{conv} \pm Q_{rad} - Diff - Evap = + S \qquad (2.3)$$

In equation (2.3), the heat storage term (S) has been given a positive value indicating that heat is being stored in the body. Under normal circumstances, heat lost by the body will be through one of the terms previously noted in equation (2.1). Only under rather cold conditions will the heat storage term be negative.

The diffusion term (Diff) covers evaporation of water that is not triggered by the thermoregulatory controls. This heat loss is normally about 11% of the basal metabolic rate. It is usually considered separately from thermoregulatory evaporation since it may occur under normal conditions even when the rate of sweat production is small. However, wearing the Chemical Defense Protective Overgarment in hot weather results in profuse sweating, and the passive diffusion term becomes insignificant. The balance may then be written as:

$$M \pm Q_{conv} \pm Q_{rad} - Evap = + S \tag{2.4}$$

The sign for the radiation term (Q_{rad}) needs to be addressed. A positive sign indicates that heat is being gained by the body, and a negative sign indicates that the body is losing heat. Use of the following equation presented by Fanger et al. [23] automatically yields the correct sign, depending on the relative magnitude of T_{cl} and T_r.

$$Q_{rad} = A_r \times e_s \times \sigma \times (T_r^4 - T_{cl}^4) \tag{2.5}$$

where:

A_r = Area of the body effective in radiating heat. For a nude body, this amounts to approx. 1.4 m^2 from a total surface area of 1.8 m^2.

e_s = The emissivity of the body.

σ = Stefan-Boltzmann constant.

T_{cl} = Absolute surface temperature of the clothing.

T_r = Absolute temperature of the surroundings.

For a soldier exposed to the sun, the Q_{rad} term in equation (2.5) will be positive due to direct solar radiation, as well as radiation from metal objects in close proximity to the soldier. Since these metal objects will be hotter than the soldier's clothing, the temperature differential (ΔT) in equation (2.5) will be positive, implying a heat <u>gain</u> instead of a heat loss. Therefore, the Q_{rad} term in equation (2.4) will be positive, keeping with the convention used in this report.

The convection term (Q_{conv}) may still be either positive or negative, depending on the temperature difference between the ambient temperature and the soldier's skin. Since the normal skin temperature is approximately 33.0°C (91.4°F), the convection term will be positive, implying a heat <u>gain</u> to the body, when the ambient temperature is above 33.3°C (92°F). Thus, for hot environments, equation (2.4) becomes:

$$M + Q_{conv} + Q_{rad} = Evap + S \qquad (2.6)$$

Equation (2.6) implies that there are two ways in which the body can respond to heat stress: either via evaporation or by storage of the heat in the body itself. The Chemical Defense Protective Overgarment,

however, severely limits the effectiveness of the evaporation process. Thus, more sweat is produced than can be evaporated, and another equation given by Fanger et al. [23] can be used to model heat loss via evaporation:

$$\text{Evap} = h_{evap} \times A_{wet} \times (P_{skin} - P_{amb}) \tag{2.7}$$

where:

h_{evap} = Heat transfer coefficient.

A_{wet} = Wetted surface area.

P_{skin} = Partial pressure of water on the skin.

P_{amb} = Partial pressure of water in air for ambient conditions.

From inspection of equation (2.7) it is apparent that the rate of heat loss through evaporation is dependent on the partial pressure difference between the wetted skin and the ambient conditions. The relative humidity of ambient air affects the rate of heat loss via evaporation. Relative humidity may be defined as [24]:

$$\text{Relative Humidity} = \frac{P_{amb}}{P_w} \times 100 \tag{2.8}$$

where:

P_w = Vapor pressure of water at the ambient temperature.

As the relative humidity increases, the partial pressure of water in air at ambient conditions (P_{amb}) also increases. This decreases the pressure differential in equation (2.7), since the partial pressure of the water on the skin (P_{skin}) is larger than the partial pressure of water in the air (P_{amb}). Therefore, the value of Evap will decrease. As this occurs, equation (2.6) indicates that heat which can no longer be lost via evaporation must be stored in the body, resulting in an increase in the storage term (S). This causes the body temperature to rise.

The normal arterial temperature for the body (T_{ar}) is 37.0°C (98.6°F) [11]. Research has shown that heat exhaustion and heat stroke will result when the arterial temperature approaches 40.5 °C (104.9°F) [25]. Above a central temperature of 37.6°C, degradation of motor skills results, which has an adverse effect on the soldier's ability to accomplish his given mission [10]. It has been reported that when the arterial temperature exceeds 38.5°C, the loss of motor skills becomes serious, especially for work requiring good hand-eye coordination (ie. flying helicopters, shooting weapon systems, etc.) [15]. Thus, preventing unacceptable elevation of central body temperatures presents a serious problem for the Army.

2.2 Wet-Bulb Globe Temperature Index

A major concern in evaluating thermal stress is determining how environmental conditions affect the severity of the stress. The four climatic conditions of interest are:

1. Air Temperature.
2. Relative Humidity.
3. Radiant Heat Load.
4. Wind Velocity.

Currently there are four temperature stress indices that have proven to be successful in evaluating heat stress for industry. These indices are: the Effective Temperature Index (ET), the Heat Stress Index (HSI), the Predicted Four-Hour Sweat Rate (P4SR), and the Wet-Bulb Globe Temperature (WBGT) [26, 11]. While all four indices are useful, the best one is the index that can be calculated with reasonable effort while still giving an accurate evaluation of the heat stress. Ease of evaluation is of paramont importance if the index is to be used by unit commanders at the Brigade level and lower, where the majority of troops are to be found. The simplest of the four indices is the WBGT index. The WBGT is based on three different temperatures, as defined by the following equation:

$$WBGT = 0.7 \times T_{WB} + 0.2 \times T_{BG} + 0.1 \times T_{DB} \qquad (2.9)$$

where:

T_{WB} = Natural wet-bulb temperature exposed to natural air movement (unaspirated).

T_{BG} = Black-globe temperature.

T_{DB} = Dry-bulb temperature.

Equation (2.9) is to be used outdoors when there is a solar load. If indoors, or outdoors with no solar load, then the black-globe temperature (T_{BG}) will approach the value of the dry-bulb temperature (T_{DB}), and equation (2.9) may be reduced to:

$$WBGT = 0.7 \times T_{WB} + 0.3 \times T_{BG} \qquad (2.10)$$

If environmental conditions change periodically, as in work/rest cycles where the individual is able to change his ambient conditions, then an average WBGT should be used. This equation is:

$$WBGT_{AVE} = \frac{(WBGT_1) \times (t_1) + \cdots + (WBGT_n) \times (t_n)}{(t_1) + \cdots + (t_n)} \qquad (2.11)$$

where:

$WBGT_n$ = The wet-bulb globe temperature for the nth set of conditions.

t_n = The amount of time spent in the nth set of conditions.

A majority of the soldiers in the Army cannot change their environmental conditions to any great extent. Therefore, this report will not consider the use of equation (2.11). Since equation (2.10) is nothing more than a special case of equation (2.9), equation (2.9) will be used in this report to calculate WBGT's.

2.3 Water Consumption and Sweat Safety Limits

The United States Army recognizes that there is a correlation between sweat production, water consumption, and thermal stress. In its survival manual the Army cautions the soldier to try to regulate his sweat production if possible, not his water intake [27]. The Army considers that water loss corresponding to ten percent dehydration of the body demands water replacement within a short period of time. This amount of water loss results in the onset of water depletion heat exhaustion [28]. Death may occur quickly if 8 - 9 quarts of water are lost without replenishment (which is approximately 10 percent dehydration of the body). Loss of four quarts of water without replenishment (approximately five percent dehydration) will cause intense thirst, a rapid heart rate, and a high body temperature [11]. The Army recommends that a soldier try to drink one quart of water every three hours when he is engaged in moderate to heavy work at a temperature of 27°C (80°F) or below. If the temperature is above 27°C, then it is recommended that one quart of water be consumed every two hours [8].

The Public Health Service conducted studies which revealed that individuals who worked in hot environments where water was not readily available tended to dehydrate more than individuals who had water easily accessible. Likewise, those who were able to receive a small amount of salt (approximately 1% in solution) with their water tended to lose less water than those who did not have salt available [11]. It was determined that if the level of dehydration exceeded 1.5 percent of the normal body weight (approximately 1.2 quarts of water), then the body temperature and heart rate would begin to increase.

Of particular interest is a study conducted by Knox, et al. [29] who studied the effects of wearing chemical defense equipment in hot weather. The test subjects were allowed to drink as much water as they wanted during scheduled rest periods. Even though the test subjects could drink water freely, on the average, they still lost more water by sweating than they drank. Over a four-hour period, the subjects lost an average of 1.36 quarts of water overall. This trend suggests that relying on thirst alone is not a good control measure for insuring that soldiers drink enough water to completely replenish the amount lost through sweating.

The actual amount of water lost by the body through sweating (measured in quarts) may be calculated as follows:

$$H_2O_{lost} = (W_{BW} - W_{AW}) \times CF_{lb\text{-}Qt} \qquad (2.12)$$

level to a published table of energy expenditures for differert activities [35]. The listed activity that most closely resembled the given example was chosen, and the average value for that activity was used to determine the work rate values for the model.

Table 5-4 of FM 21-40 describes the limiting values listed as those that will insure 'minimal' casualties. This implies that a physiological condition must be chosen which defines when a certain percentage of soldiers are likely to become heat casualties. A study conducted by Shvartz, et al. [36] defined a rectal temperature (T_{re}) of $39^{o}C$ as the tolerance limit. Goldman [16] determined that at a deep body temperature of $39.2^{o}C$, along with high skin temperatures, there was a 25% risk of subjects' experiencing heat exhaustion collapse.

A review of published Army documents was conducted in order to determine the Army definition of minimal and negligible casualties. In the area of chemical weapons, the only criterion in use is whether or not to eliminate agent use [37]. According to the criterion, chemical agents can be used, or not used, depending on whether friendly troops or civilians are within the Downwind Hazard Distance (DWHD). No criterion was found for chemical casualty risks. However, there is a published criterion for troop risk for nuclear weapons [38, 39]. Table 3-2, on page 41, outlines the risk criteria for troops. According to FM 101-31-3, a casualty is defined as someone who receives at least 650 rad, which is the median lethal dosage (LD_{50}) for radiation. Nuisance

Table 3-1: MOPP Levels Used in Tables From FM 21-40 [22]

MOPP Level	Clothing/Equipment Worn
1	Fatigues with mask.
2	Fatigues with mask, hood, gloves, and body armor.
3	Chemical Defense Protective Overgarment worn over fatigues.
4	Chemical Defense Protective Overgarment worn over fatigues and body armor. Mask, hood, and gloves worn.

that the last division actually represented a temperature range instead of a single temperature and, therefore, a temperature of 38.0°C (100.4°F) was used. Since no humidities were given in the table, a representative humidity of 50% was chosen for the simulations. The following is a tabulation of examples given in FM 21-40 for the three work rates used in the tables [22]. These same examples are also used in FM 3-4.

1. Low - Motorized movement or administrative work.
2. Moderate - Improvement of position or reserve position activity.
3. Heavy - Infantry dismounted assault or forced march.

Metabolic rates of 200, 350, and 500 watts were assigned to the low, moderate, and heavy work loads, respectively. These values were determined by comparing the given examples from FM 21-40 for each work

TABLE 5-4. MAXIMUM TIMES (MINUTES) WITH MINIMUM HEAT CASUALTIES					
MOPP LEVEL	WORK RATE	TEMPERATURE RANGES			
		21°C (70°F)	21°-26°C (70°-79°F)	27°-32°C (80°-89°F)	33°C (90°F)
1	LOW	XX	XX	XX	XX
	MODERATE	XX	XX	XX	100
	HEAVY	XX	XX	110	50
2	LOW	XX	XX	XX	XX
	MODERATE	XX	XX	XX	65
	HEAVY	XX	170	65	45
3	LOW	XX	XX	XX	XX
	MODERATE	XX	XX	140	55
	HEAVY	200	95	55	40
4	LOW	XX	XX	XX	80
	MODERATE	XX	115	65	40
	HEAVY	60	50	40	30

WARNING: This table is intended as a guide only. Maximum work times may be adjusted up or down based on field experience.

Figure 3-2: Table 5-4 from FM 21-40 [22]

Therefore, only the MOPP-IV level from Table 5-4 of FM 21-40 was used in the validation process.

In order to run the computer model, the physical parameters for the Chemical Defense Protective Overgarment and the other MOPP-IV gear must be specified. The values computed by Peterson [32] were used in lieu of other published data. Peterson's values were chosen since they were based on experimental data provided by Goldman, Frye, and Nunneley [34]. It was found that previously published parameters derived from 'copper manikin' data did not adequately describe the Chemical Defense Protective Overgarment.

Another input value is the allowance for evaporation to the environment from various elements. Since the gloves, overboots, and mask/hood are all made of rubber or butyl-rubber, there is no evaporation from the head, hands, or feet. Evaporation from all other elements was allowed within the limits of the garments worn on those elements.

Environmental temperatures, humidity, and the work level also have to be specified for a given case. The field manual specifies the environmental conditions soley on the basis of temperature. As shown in Figure 3-2, the four classes are: 21°C (70°F), 21 - 26°C (70 - 79°F), 27 - 32°C (80 - 89°F), and 33°C (90°F). For the middle ranges, the upper temperature for each range was used. It was assumed

Peterson also compared calculated values of the arterial temperature with experimental values measured by Brown, et al. [32, 15] for subjects wearing LCV's. Two LCV's were compared: the Royal Aircraft Establishment LCV (RAE LCV) and the Life Support Systems, INC. LCV (LSS LCV). The test duration was two hours, with work/rest cycles being used. Subjects were dressed in flight suits with helmets and boots. The results of the comparison revealed that the model was able to accurately calculate the rate of change in the arterial temperature for subjects wearing an LCV.

3.3 Validation for Current Study

3.3.1 Basis for Study and Input Data for Model

For the current study, Table 5-4, Maximum Times with Minimum Heat Casualties, from FM 21-40, was used as the basis of comparison for validation purposes. See Figure 3-2, on page 38, for a copy of Table 5-4 from FM 21-40. This table was chosen because the values in the table were derived from an empirically formulated model developed by Goldman while at the US Army NATICK Laboritories [33]. As noted earlier, the MOPP levels used in the development of the tables in Chapter five of FM 21-40 do not correspond to the MOPP levels currently in use in the Army. The MOPP levels used in the tables in FM 21-40 are listed in Table 3-1, on page 39. A comparison of Tables 1-1 and 3-1 reveals that only the MOPP-IV level from both tables are the same.

arterial temperature and sweat rate. Since the metabolic rate is specified in the program, the metabolic values were obviously identical. The computed mean skin temperature was only approximately in agreement with measured values due to the complicated physical responses that influence skin temperature. Thus, the model was validated for arterial temperature and sweat rate in hyperthermal situations.

3.2.2 Validation for Chemical Defense Protective Overgarment and LCV's

A recent study conducted by Peterson [32] compared calculated results for subjects wearing the U.S. Chemical Defense Protective Overgarment to experimental values obtained from an Australian study. Two cases were compared. The first case was for a thick forest environment (86°F, RH = 61%, no wind, no sunlight). The second case was for open ground (91°F, RH = 39%, wind speed = 2.6 m/sec, 10°C solar load). In both cases the predicted temperatures were lower than the experimental values, but the rates at which the arterial temperature increased were nearly identical to the rate of increase of the rectal temperature. The difference can be attributed to the initial conditions. The model assumed an arterial temperature of 37.0°C while the initial rectal temperature was higher, which is most likely due to the fact that the subjects had to go through a dressing procedure which subjected them to the heat while donning the ensembles. When the initial difference is taken into account, the predicted arterial temperatures are in very good agreement with experimental results.

3.2 Previous Validations of the Model

3.2.1 General Validations

Wissler's model has been developed over a span of twenty years. Throughout its development, which is still on-going, the model has been compared against various sets of experimental data in order to validate it. Wissler has documented five different cases used for validation of the model [31]. These cases are described below.

1. Exercise at three progressively increasing rates at air temperatures of 10°C, 20°C, and 30°C. Each test covered three hours. Rectal, esophageal, and mean skin temperatures, metabolic rate, and rate of sweating were compared to values found experimentally by Saltin, et al.

2. Head-out immersion in 18.5°C water for one hour. Rectal temperature was compared to results obtained by Påsche, et al.

3. Exposure to hyperbaric heliox (He/O_2) mixtures at 18°C for two hours. Rectal temperature, 12 skin temperatures, and four thermal fluxes were compared to values reported by Påsche, et al.

4. Head-out immersion of lightly clothed subjects in cold water while either resting or swimming. Rectal temperatures and metabolic rates were compared to data obtained by Hayward.

5. Head-out immersion in 10°C water for one hour followed by rapid rewarming in warm water (28 - 40°C). Tympanic and rectal temperatures and metabolic rates were compared to values measured in a study by Hayward, et al.

Since the first case is the only one that deals with heat stress, it will be the only one discussed here. Wissler found that there was good agreement between predicted and measured values for both

Subroutines required by the main program allow for specification of the characteristics of clothing worn by the subject. Properties such as garment thickness, conductivity, density, permeability, and specific heat are used to calculate the clo values for the garments, as well as mass transfer coefficients for water vapor. Due to the radial design, the clothing is modeled in a layered fashion, which provides the ability to 'dress' the subject layer-by-layer. A liquid-cooled garment (LCG) may also be included in the garment at the appropriate position (ie. next to the skin or over the clothing). Input values for the LCG include flowrate, inlet temperature, and flow pattern. An overall heat transfer coefficient (U) for the LCG is calculated from the physical properties of the garment.

The program has the ability to model a time-dependent profile of environmental conditions and metabolic rates within the same run. This allows one to model a variety of work/rest cycles. Input variables include environmental properties, work load, and type of work performed.

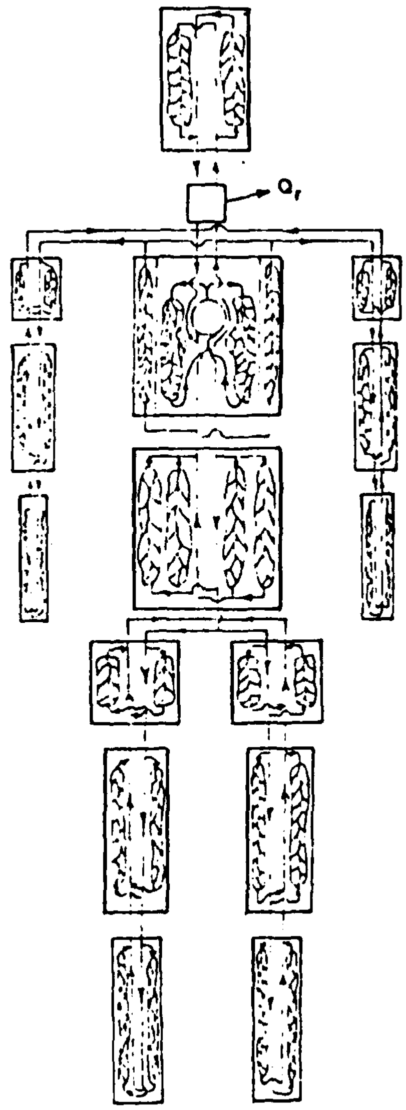

Figure 3-1: Wissler's 15-Element Man [30]

the arms, legs, head, chest and abdominal regions of the body. See Figure 3-1 on page 32 for a diagram showing the major elements. Each element is composed of radial layers that approximate the physical regions corresponding to bone, tissue, fat, and skin. Likewise, a vascular system representing the arteries, veins, and capillaries is included in each element.

Variables within each cylindrical element are dependent upon radial position and time unless they are time-independent (ie. specific heat). Each radial shell has its own time-dependent temperature, and the elements are linked by the vascular system, as well as conditions that provide for continuity of temperature and thermal flux between the shells. The amount of heat brought to the surface of each element is limited to the amount of heat transferred from that element to the environment. The heat produced in an element by metabolic reactions is either stored, transferred to another element by conduction or by the vascular system, or conducted to the surface of the element.

The initial conditions for the subject are provided as input in order to specify the initial temperature for each element. The transient-state heat conduction equation is solved by finite-difference techniques. Similar mass transfer equations are solved in the same fashion. Typical values required by the program include parameters that adjust sweat production, vascular responses to heat stress, and subject height, weight, and percent body fat. These conditions remain constant during execution.

Chapter 3

Mathematical Model and its Validation

3.1 Mathematical Model

The task of creating a mathematical computer model of the human thermal regulatory system is a formidable project. The model must be able to describe accurately heat transfer within the human body. The model must also accurately describe body mechanisms which regulate transfer of heat from the skin to the environment, as well as the effect that storage of heat (or lack thereof) has on different parts of the body. Furthermore, the description of boundary conditions must be realistic and unsteady-state conditions must be dealt with, leading to the use of complex equations. Such a model has been developed by Dr. E. H. Wissler from the University of Texas at Austin. This report will provide a brief overview of Wissler's model and its capabilities. For details pertaining to the equations used in the model, see the cited references [23, 30, 31].

The model developed by Wissler is composed of a 15-element man, with each element being cylindrical in nature. These elements represent

Table 2-1: Recommended Standards and Amounts of Water Lost

RECOMMENDED STANDARD	PBWS	ACTUAL AMOUNT OF H2O LOST
NIOSH	1.5 %	2.16 Qts
*	5.0 %	4.85 Qts
Army Survival	10.0 %	8.69 Qts

NOTE - '*' represents an experimental point of significance. It is not a standard.

intense thirst. Clearly the standard chosen should be closer to the NIOSH standard than the experimental point if the soldier is to perform his mission with any degree of reliability. This report will use a standard that is one-third of the way between the NIOSH standard and the experimental point. This arbitrary standard is at 2.67% of the body weight, or approximately 3.0 quarts of water actually lost. This standard should be verified by experimentation to determine its validity.

amount of water that the soldier can lose given a particular percentage of the body weight that may be lost through sweating is:

$$H_2O_{lost} = \frac{(160 \times PBWS \times CF_{lb\text{-}Qt})}{100} + 1 \qquad (2.14)$$

Equation (2.14) implies that one additional quart of water may be lost for any given PBWS, which takes into account the quart of water that is replaced by drinking. Rearranging equation (2.14) and solving for the percentage of the body weight that is lost through sweating gives:

$$PBWS = \frac{(H_2O_{lost} - 1)}{(160 \times CF_{lb\text{-}Qt})} \times 100 \qquad (2.15)$$

Solving equation (2.15) for the three previously mentioned PBWS percentages leads to Table 2-1, on page 29.

Although the Army accepts a ten percent dehydration as an upper limit, it must be remembered that this limit is for survival purposes only. Therefore, a standard must be chosen that will allow soldiers to continue their mission, not merely survive. The NIOSH standard is 1.5 percent. At this point the body temperature, heart rate, and thirst first start to rise. The five percent figure cited is where the individual has an elevated body temperature, a high heart rate, and

where:

W_{BW} = Weight of body before work [=] lbs.

W_{AW} = Weight of body after work [=] lbs.

CF_{lb-Qt} = Conversion factor [=] 0.48077 quarts/lb using a water weight of 8.32 lb/gal.

Equation (2.12) may be converted to use for the "average man" as shown below.

$$H_2O_{lost} = \frac{(160 \times PBWS \times CF_{lb-Qt})}{100} \tag{2.13}$$

where:

160 = Average man's weight [=] lb.

PBWS = Percent of body weight lost due to sweat.

Most Army troops carry only one 1-quart canteen, while special units (ie. Ranger, Special Forces, Airborne, Air Assault, etc.) are authorized two 1-quart canteens. The reason for the difference in the basis of issue is that conventional units are supposed to have greater access to additional water. Special units are expected to forage for their drinking water until additional water can be supplied from conventional units. Assuming that the soldier drinks his one quart of water at the same rate that he loses water due to sweating, the actual

effects are defined as those injuries that render a soldier combat ineffective; such as vomiting, injuries due to blast effects, and severe thermal burns. The United States Army Nuclear and Chemical Agency (USANCA) recently completed development of criteria for NBC survivability for materiel [40]. USANCA defined 'negligible risk' to chemical agents as being up to five percent of a unit's personnel becoming mildly incapacitated. Mild incapacitation is equivalent to rendering the soldier combat ineffective.

Table 3-2: Nuclear Risk Criteria for Troop Safety [38]

Risk Level	Percent Casualties	Percent Nuisance Effects
Negligible	1.0%	2.5%
Moderate	2.5%	5.0%
Emergency	5.0%	not specified

As mentioned earlier (see Section 2.1 on page 22), when the arterial temperature (T_{ar}) exceeds 38.5°C, work requiring good hand-eye coordination becomes difficult to perform. This suggests that the soldier who needs good hand-eye coordination in his job will become combat ineffective when his arterial temperature exceeds 38.5°C. Another mildly incapacitating injury is heat exhaustion. Heat exhaustion, unlike heat stroke, can usually be treated by merely getting the victim to rest in a cool area and drink water. Heat exhaustion normally occurs when the rectal temperature is between 37.5 -

38.3°C (99.5 - 101°F) [11]. This temperature range, however, is affected by the physical condition of the individual. Thus, soldiers, who for the most part are in better physical condition than their civilian counterparts, should be able to tolerate a slightly higher rectal temperature.

NIOSH recommends that the deep body temperature not exceed 38°C (100.4°F) [11]. This standard is for negligible heat injuries in industry. Negligible here means that up to five percent of the work force may become incapacitated. NIOSH stated that above 38°C, the risk of heat injury gradually increases. Thus, if the definition for negligible risk presented by USANCA is used along with the information given in the last paragraph, an arterial temperature above 38.0°C can be used for the physiological condition that defines limiting heat stress. This report recommends that the values given in Table 3-3, on page 43, be used as standards. The table includes a stricter standard for pilots due to the critical nature of good hand-eye coordination in their mission performance and safety. An arterial temperature of 39.0°C was chosen as the limit for minimal risk since 'minimal' suggests that a less rigid standard can be used than the one used for negligible risk .

Table 3-3: Recommended Temperatures for Negligible and Minimal Risk

Risk Level	Arterial Temperature (C)	Standard For:
Negligible	38.0	Pilots
	38.5	All Others
Minimal	38.5	Pilots
	39.0	All Others

3.3.2 Results of Model Runs and Comparison with Basis

Table 3-4, on page 44, compares the calculated tolerance times obtained from the model and the tolerance times given in Table 5-4 of FM 21-40. The calculated values are the times required to reach the minimal risk criterion for all personnel, except pilots, as given in Table 3-3. The input values were chosen as discussed in Section 3.3.1. A review of the values listed in Table 3-4 shows that there is good agreement between the calculated values and the basis values for a soldier in MOPP-IV. The differences in the values may be attributed to differences in the environmental conditions, or in the actual standards used for the basis. Table 3-4 suggests that Wissler's model may be used to predict tolerance times for personnel in MOPP-IV. Thus, the model will be used to evaluate the work/rest cycles given in Table 5-2 of FM 21-40, to evaluate the effect of humidity on performance, and to estimate water loss for various conditions.

Table 3-4: Comparison of Model Results to Basis Values

Work Level	Temperature (F)	Tolerance Time (min) Basis	Model	Percent Difference
Low	100	80	94	+18.37
Moderate	79	115	122	+ 6.5
	89	65	67	+ 4.15
	100	40	46	+15.75
Heavy	70	60	62	+ 4.2
	79	50	48	- 3.6
	89	40	37	- 7.0
	100	30	28	- 4.0

Chapter 4

Presentation and Discussion of Results

4.1 Continuous Work

The mission of the United States Army is to win wars. The mission of the Infantry is to close with and destroy the enemy by close combat and assault. In essence, the Infantry is designed to fight until it takes the objective or is repulsed. When in combat, there are no opportunities to rest and relax. Every minute is a struggle to survive. The soldier must continue his mission until it is achieved, or until he is no longer able to go on.

Many times the situation is such that time is of the essence. In these cases, the commander does not have the luxury of allowing his troops to take breaks. During these times, achieving the mission comes before all else, for if the mission is not accomplished on time, the result may be disastrous. The commander, however, must try at all times to insure the safety of his troops. This implies that the commander needs to know the limit of his men's capabilities, and if possible, not exceed those capabilities. This includes knowing the effect of thermal stress on his troops' capacity for continuous work.

4.1.1 Results

The maximum continuous work times presented in Figure 3-2, Section 3.3.1, and Table 5-4 of FM 21-40 (see page 38) do not consider the effect of humidity and/or sweat production on the risk to the soldier. Therefore, model runs were conducted so that these parameters could be considered in detail. Three relative humidities (20%, 50%, and 80%) were chosen in order to look at the entire spectrum. These three humidities simulate desert, temperate, and tropical environments, respectively. Likewise, the amount of sweat produced was calculated in order to determine whether loss of water from the body could be a limiting factor in causing heat casualties.

Figures 4-1 thru 4-24, on pages 47- 58, are graphical representations of the data collected from the model runs for the different work levels and temperatures in Figure 3-2, Section 3.3.1, and Table 5-4 from FM 21-40. All cases were run at the three humidities, except for the case of a temperature of 21°C (70°F) and a relative humidity of 20%. This particular case was not evaluated since the adjacent cases (same temperature with a higher relative humidity, and same humidity with a higher temperature) were both stable in terms of the arterial temperature. Hence, this case would also be stable.

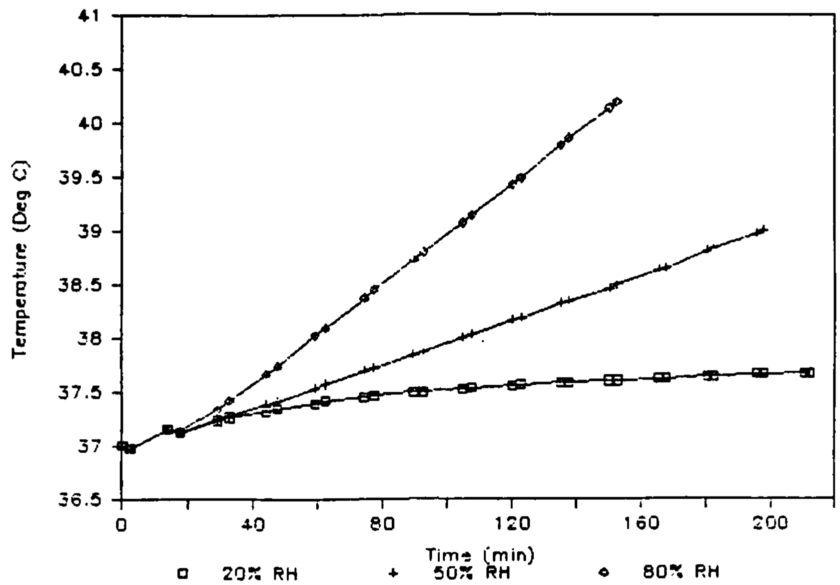

Figure 4-1: T_{ar} vs. Time. Low Continuous Work, 33°C

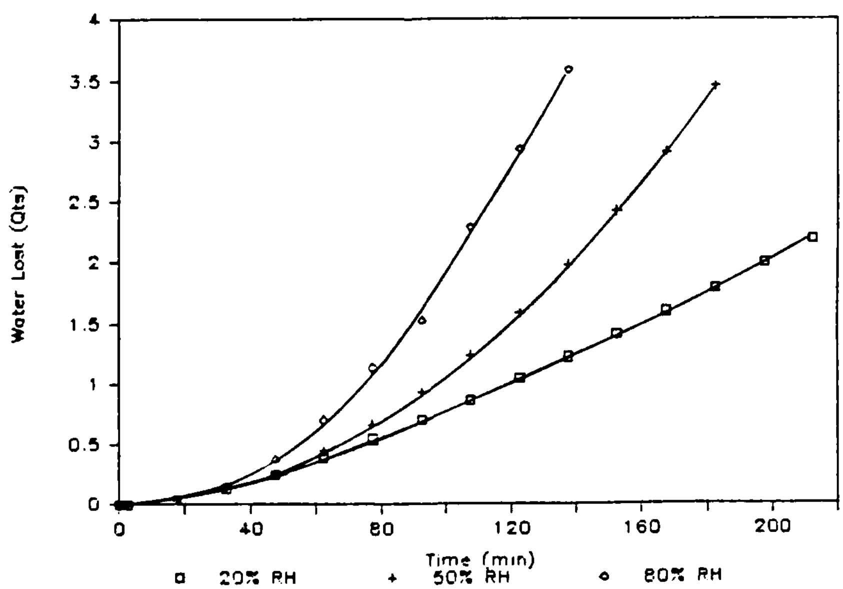

Figure 4-2: Water Lost vs. Time. Low Continuous Work, 33°C

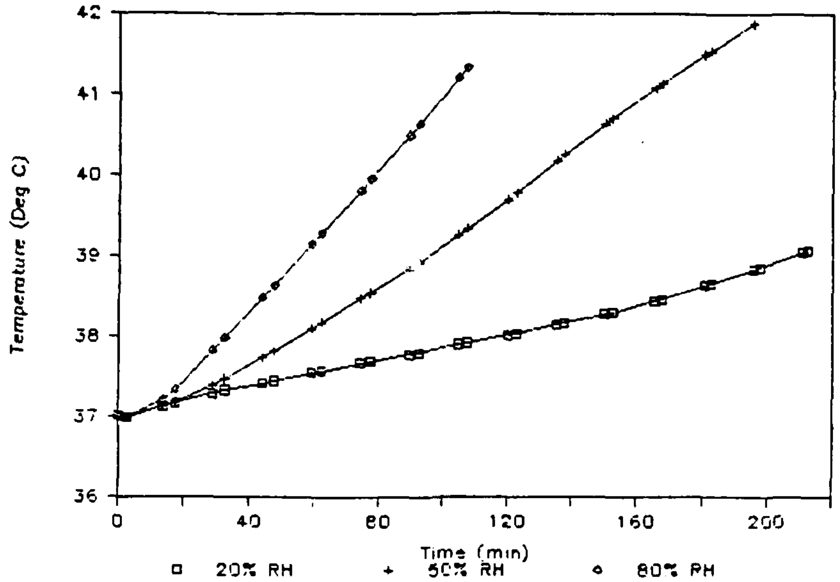

Figure 4-3: T_{ar} vs. Time. Low Continuous Work, 38°C

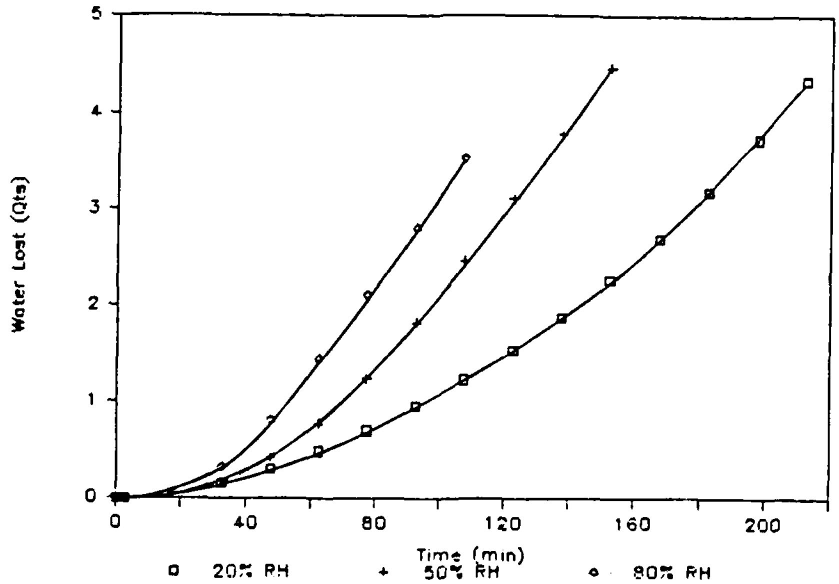

Figure 4-4: Water Lost vs. Time. Low Continuous Work, 38°C

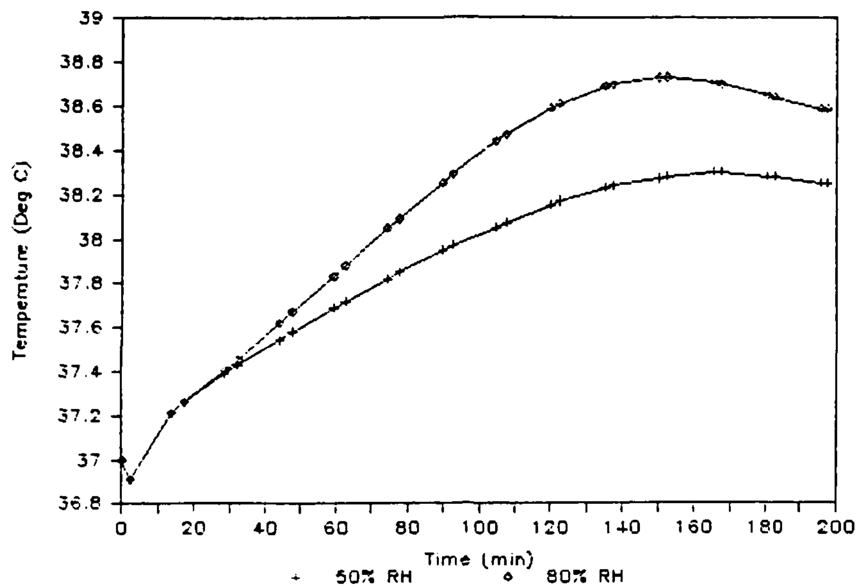

Figure 4-5: T_{ar} vs. ˙ime. Moderate Continuous Work, 21°C

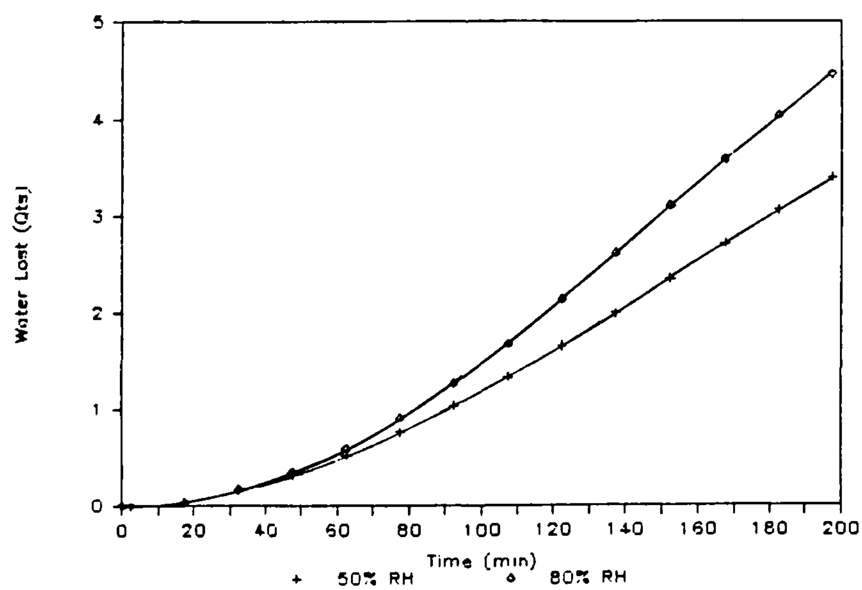

Figure 4-6: Water Lost vs. Time. Moderate Continuous Work, 21°C

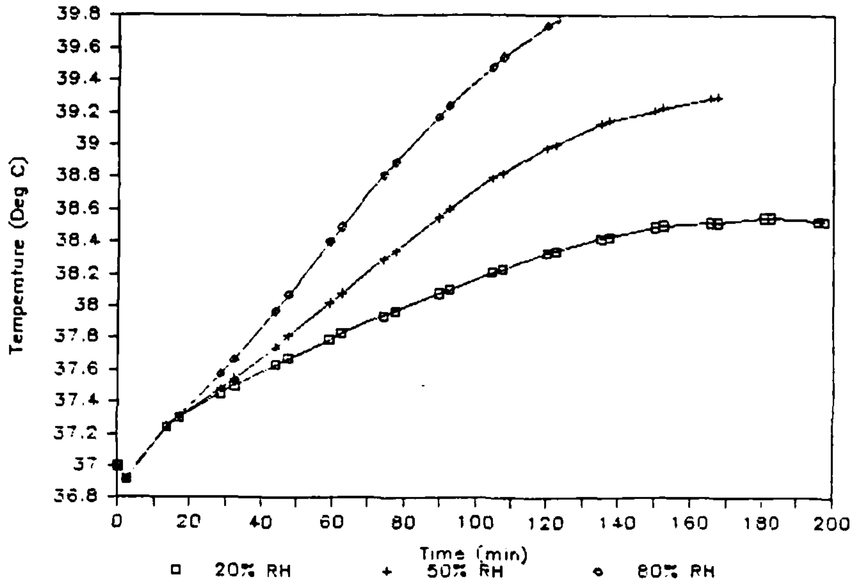

Figure 4-7: T_{ar} vs. Time. Moderate Continuous Work, 26°C

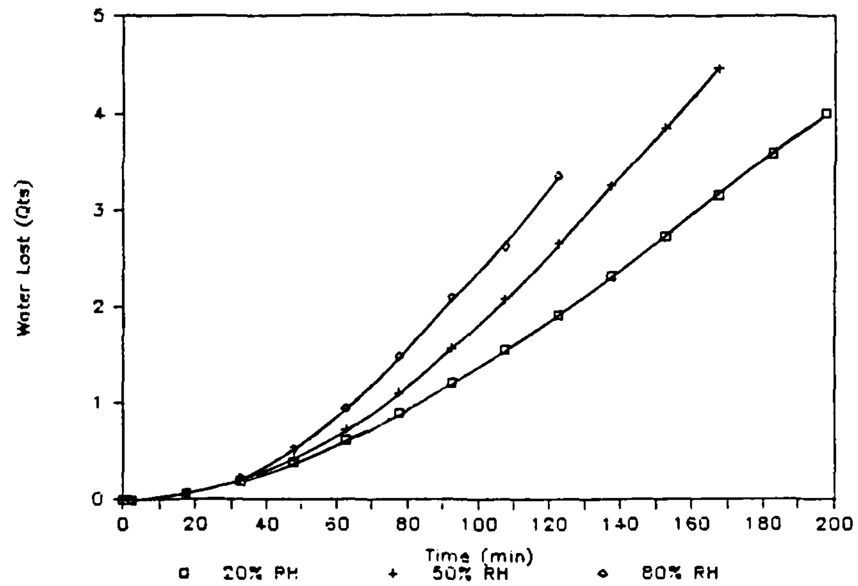

Figure 4-8: Water Lost vs. Time. Moderate Continuous Work, 26°C

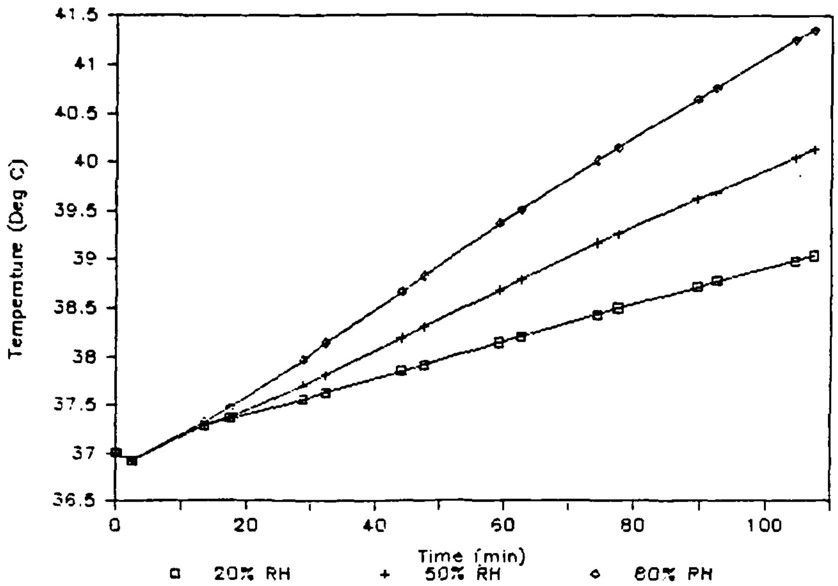

Figure 4-9: T_{ar} vs. Time. Moderate Continuous Work, 32°C

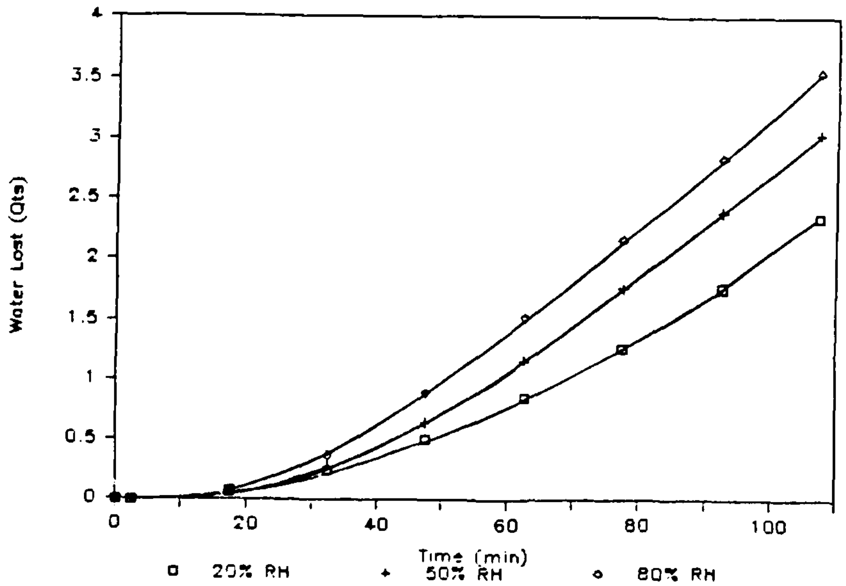

Figure 4-10: Water Lost vs. Time. Moderate Continuous Work, 32°C

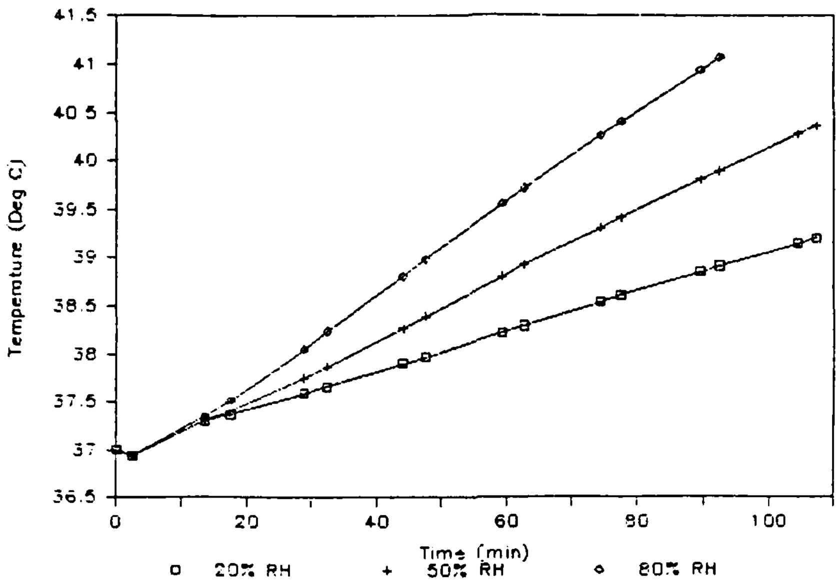

Figure 4-11: T_{ar} vs. Time. Moderate Continuous Work, 33°C

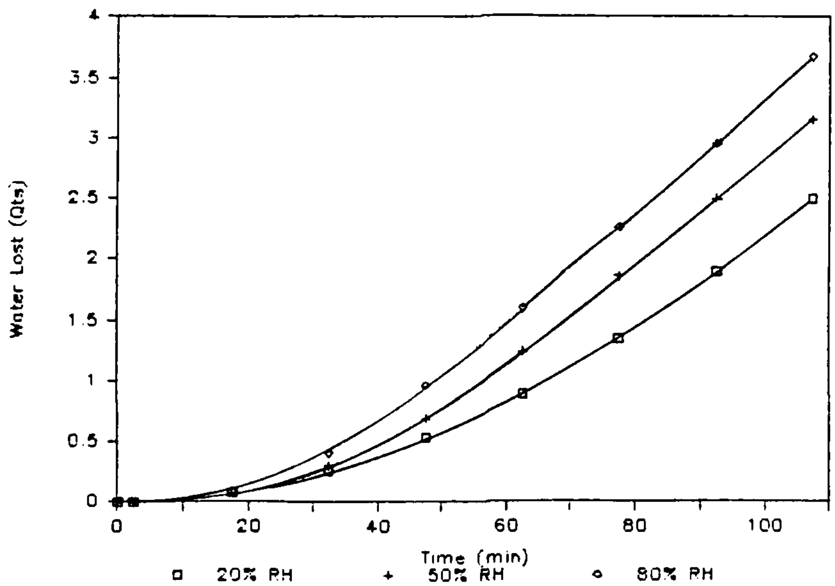

Figure 4-12: Water Lost vs. Time. Moderate Continuous Work, 33°C

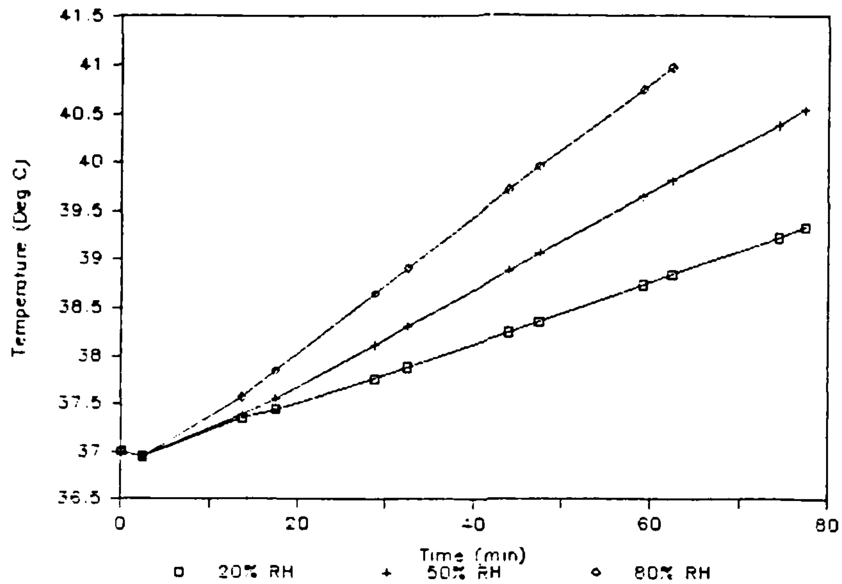

Figure 4-13: T_{ar} vs. Time. Moderate Continuous Work, 38°C

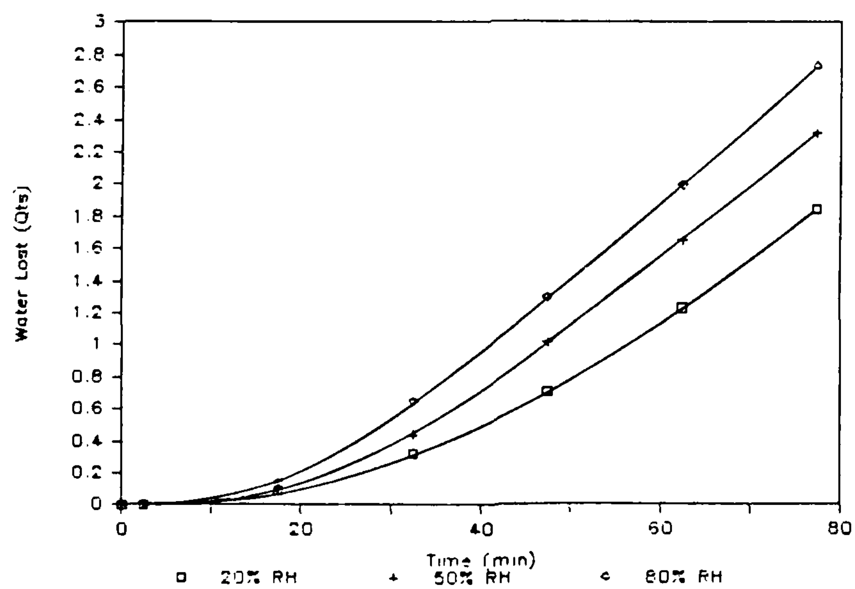

Figure 4-14: Water Lost vs. Time. Moderate Continuous Work, 38°C

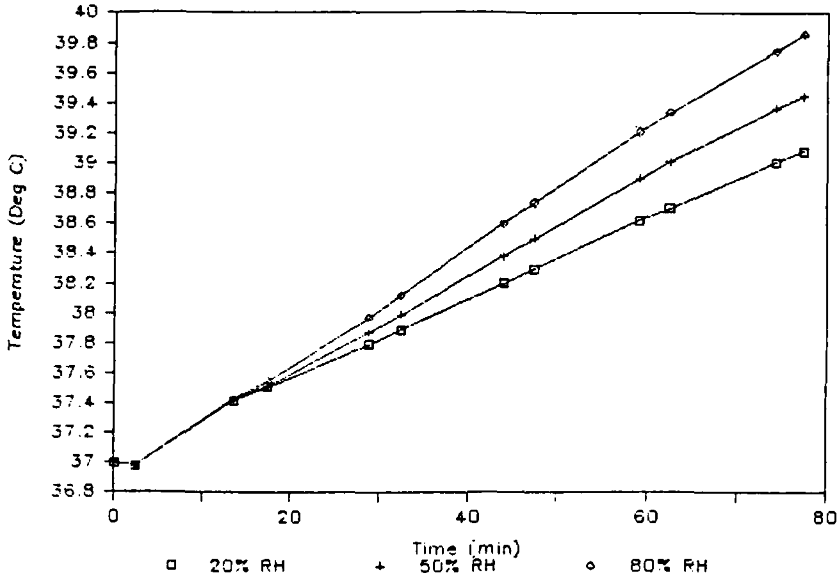

Figure 4-15: T_{ar} vs. Time. Heavy Continuous Work, 21°C

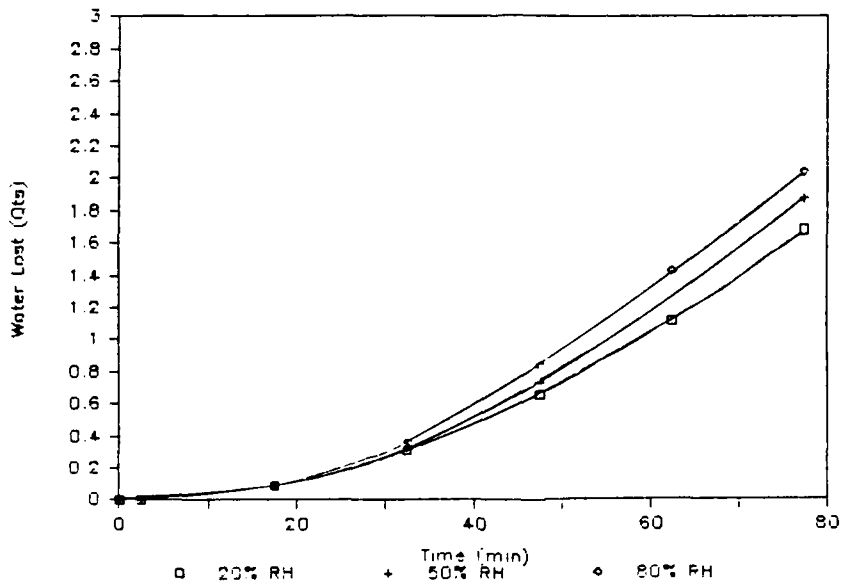

Figure 4-16: Water Lost vs. Time. Heavy Continuous Work, 21°C

4.2.1 Results

Figures 4-28 thru 4-45, on pages 69-77, display data collected from the computer model runs. The work/rest cycles used in the runs correspond to the work/rest cycles given in Figure 4-27, Section 4.2, and Table 5-2 of FM 21-40. The work parameters were chosen in the manner previously discussed in Section 3.3.1. For the rest period, the metabolic rate was reduced to the resting metabolic rate (430 BTU/HR) [23]. The environmental conditions were not changed between the two periods. Two additional cases besides the ones from Table 5-2 were run. These cases were: 38°C, moderate work, and 26°C, heavy work. It was felt that these two cases may have a work/rest cycle that is within the time limits discussed in Section 4.2.

TABLE 5-2. CYCLIC WORK/REST VALUES (MINUTES) WITH NEGLIGIBLE HEAT CASUALTIES

MOPP LEVEL [a]	WORK RATE	TEMPERATURE RANGES [d] 21°C (70°F)	21° - 26°C (70° - 79°F)	27° - 32°C (80° - 89°F)	33°C (90°F)
1	LOW	b	b	b	b
	MODERATE	b	b	60/20	40/50
	HEAVY	b	60/15	40/25	30/60
2	LOW	b	b	b	50/50
	MODERATE	b	b	60/35	30/60
	HEAVY	60/30	45/30	25/30	c
3	LOW	b	b	b	60/30
	MODERATE	b	60/20	40/35	30/50
	HEAVY	40/20	35/30	c	c
4	LOW	b	b	40/30	20/50
	MODERATE	40/20	30/25	20/40	c
	HEAVY	20/25	c	c	c

WARNING: This table is intended as a guide only. The work/rest values given may be adjusted up or down based on experience in the field by the commander.

Figure 4-27: Table 5-2 from FM 21-40 [22]

under ten minutes. This was also true for a majority of tasks with time standards found in the unit ARTEP manuals. This makes sense because most of the tasks are broken down into small blocks of individual and small group tasks. These tasks normally can be done in a short period of time. Likewise, most things that need to be accomplished in battle (ie. call for fire support, firing a weapon, first-aid, etc.) need to be done as quickly as possible. Therefore, it seems appropriate to limit the minimum work time to ten minutes. This implies that a majority of tasks at the individual level can be done on the work/rest cycle, which in turn will allow the unit to accomplish its mission. It is felt that the maximum time spent in the rest period should be limited to 50 minutes. At this level, the soldier will do a minimum of ten minutes of work per hour. This equates to one hour of work every six hours, or a reduction to one-sixth the normal work output. Any further reduction will most likely jeopardize the mission.

Figure 4-27, on page 67, shows Table 5-2 from FM 21-40. This table will be used as the basis for the discussion of computed results for various work/rest cycles.

4.2 Cyclic Work

Work/rest cycles are used to provide an opportunity for lowering body heat content by reducing the metabolic rate and, if possible, changing the environmental conditions in order to facilitate heat loss through the skin. For the majority of Army personnel, changing environmental conditions is limited to finding shade or a cool place to rest. Therefore, the major factors are reduction of the metabolic rate and the amount of time spent working as oppossed to resting.

The commander must strike a balance between the safety of his men and accomplishment of the mission. If he favors either objective too greatly, lives may be lost. The commander who does not implement work/rest cycles in hot weather, if the situation permits, is inviting unnecessary heat casualties, and when too many soldiers become heat casualties, the unit will not be able to perform its assigned mission. Likewise, the commander can be so safety conscious that he reduces the work time too much, with the result that the unit fails to accomplish its mission on time. The question is how much can the work time be reduced without sacrificing the mission.

In order to determine the minimum work time, a review of Soldiers' Manuals (SM's) and Army Training and Evaluation Program manuals (ARTEP's) was conducted [41]. It was found that for a majority of individual soldier tasks involving a time standard, the limit was

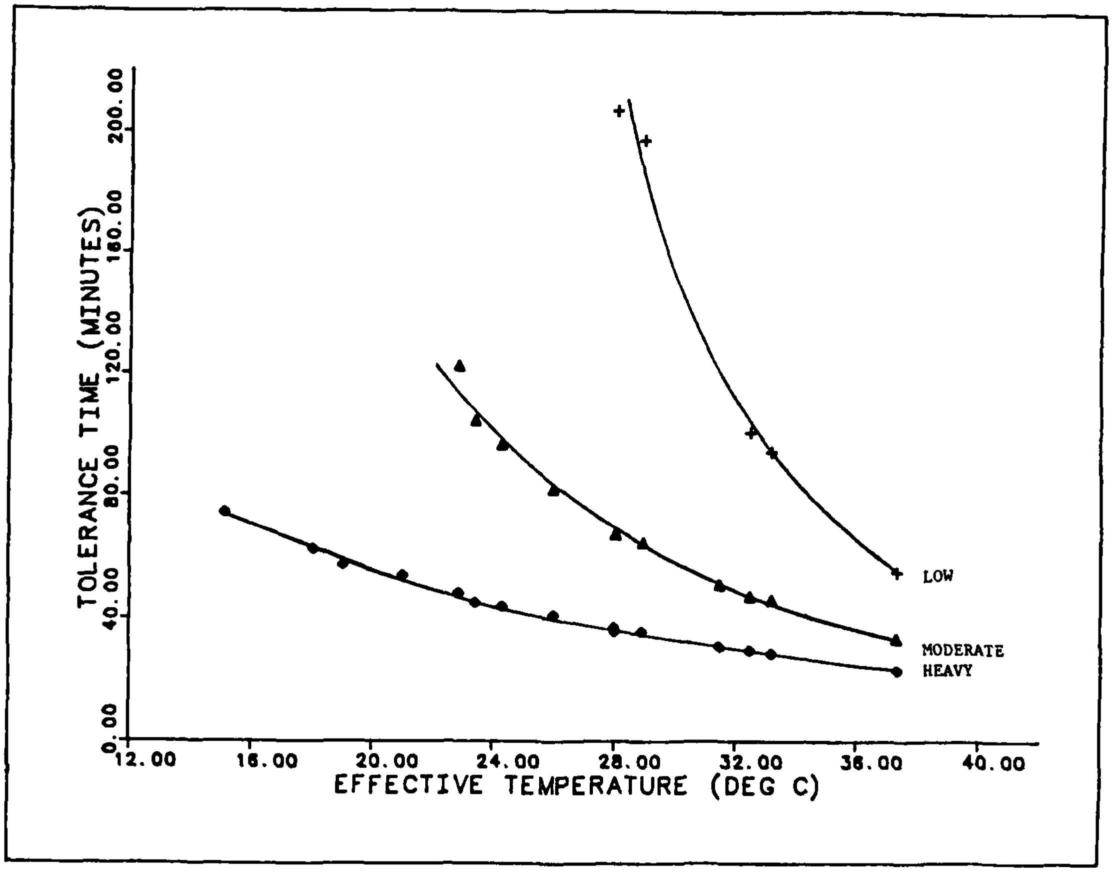

Figure 4-26: Tolerance Times vs. $T_{EFF\text{-}WBGT[mod]}$

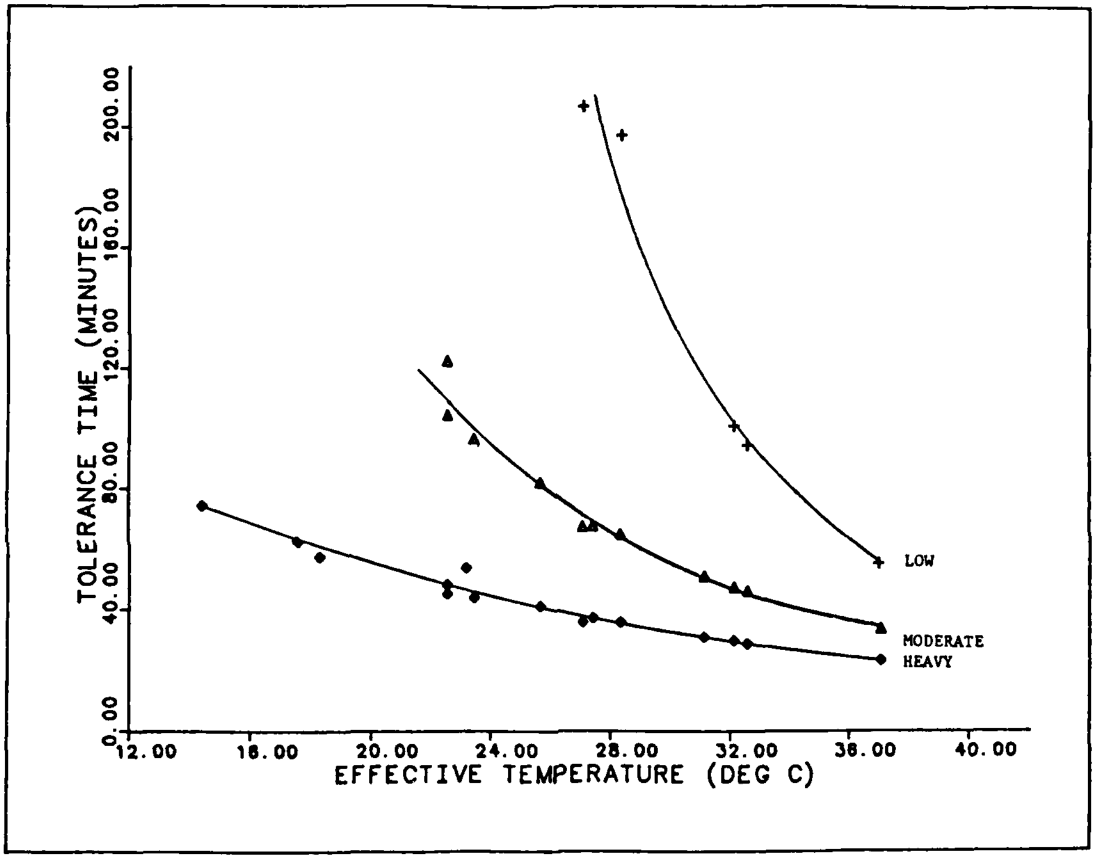

Figure 4-25: Tolerance Times vs. $T_{EFF-WBGT}$

low work at low effective temperatures. This problem, however, is offset by the knowledge that in this area, the body temperature may become stabilized, and, therefore, the amount of water lost by the body may be more important than the body temperature. A partial solution to this problem is to include a warning statement below the figure informing users that water loss must be considered when dealing with low work rates and low effective temperatures.

5-4 of FM 21-40 for different humidities. As discussed in Section 2.2, the WBGT is a simple but effective way to include the effects of humidity and solar heat load into an analysis.

The tolerance times shown in Figure 4-25, were obtained by using equation (2.9), to calculate the effective temperature (T_{eff}). As can be seen, the deviation of the data points from the curves, while not great, is large enough to warrant revision. Data presented in Figure 4-26, reveal that a better correlation is obtained when equation (4.1) is used to calculate an effective temperature.

$$WBGT_{mod} = 0.66 \times T_{WB} + 0.24 \times T_{BG} + 0.1 \times T_{DB} \tag{4.1}$$

Equation (4.1) merely involves a modification of the coefficients found in equation (2.9). When equation (4.1)is used, the resulting deviation of the data points from the curve is much less than when equation (2.9) is used. This implies that Figure 4-26 can be used to predict tolerance times for soldiers in MOPP-IV at different climatic conditions.

It must be noted here that, although Figure 4-26 allows prediction of tolerance times in many varied climates, caution must be exercised in the use of this figure. Specifically, the deviations from the curves increase as the effective temperature and the level of work decrease. Hence, the error in predicted tolerance times is greatest for

Table 4-1: Water Loss Limiting Cases

Work Level	Temperature (C)	Relative Humidity	Time to Reach Safety Limit (min) Water Loss	Arterial Temperature
Low	33	50%	170	198
		20%	270 (est)	Stabilized
	38	20%	177	208
Moderate	21	80%	152	Stabilized
		50%	183	Stabilized
	26	20%	163	Stabilized

NOTE: (est) = Estimated value. Extrapolated from graph.

This observation indicates that soldiers who are exposed to moderate temperatures (temperate climates), or soldiers who have reduced work loads in hot environments, are apt to dehydrate before elevated arterial temperatures become a limiting factor. Thus, the commander who reduces the work load of soldiers in his command must still insure that his troops receive sufficient water in order to prevent dehydration. This problem will be discussed more completely in Section 4.2.

4.1.3 Development of a Continuous Work versus Tolerance Times Graph

Clearly, humidity does ·ave an effect on the tolerance times for a given temperature. The effect is significant at lower temperatures and for lower work rates. Therefore, the problem is how to include the effect of humidity without having to develop numerous tables like Table

4.1.2 Comparison of Model Results to Basis

As previously discussed in Section 3.3.2, the basis values and the calculated values obtained from the model for a relative humidity of 50% are in close agreement. However, values calculated for relative humidities of 20% and 80% are markedly different from values given in Table 5-2 from FM 21-40. From inspection of the figures in Section 4.1.1, the effect of humidity on arterial temperature and amount of water loss is apparent. Without fail, as the humidity increases while all other parameters remain constant, the arterial temperature and the amount of water loss both increase. It is interesting to note that as the environmental temperature increases, the effect of humidity on arterial temperature becomes greater, while its effect on the amount of water loss diminishes. Also, as the work rate increases, the effect of humidity on both arterial temperature and the amount of water loss decreases. The above analysis suggests that the humidity will have its greatest effect on soldiers who are in warmer environments, but are not doing strenuous work. In particular, the tropical environment is where this will occur due to its high temperatures and humidities.

A comparison of limiting conditions (arterial temperatures less than 39°C and cumulative water loss less than 3 Qts) for various cases reveals that the amount of water loss is the limiting factor at low work levels with low humidities. See Table 4-1, on page 60, for specific details.

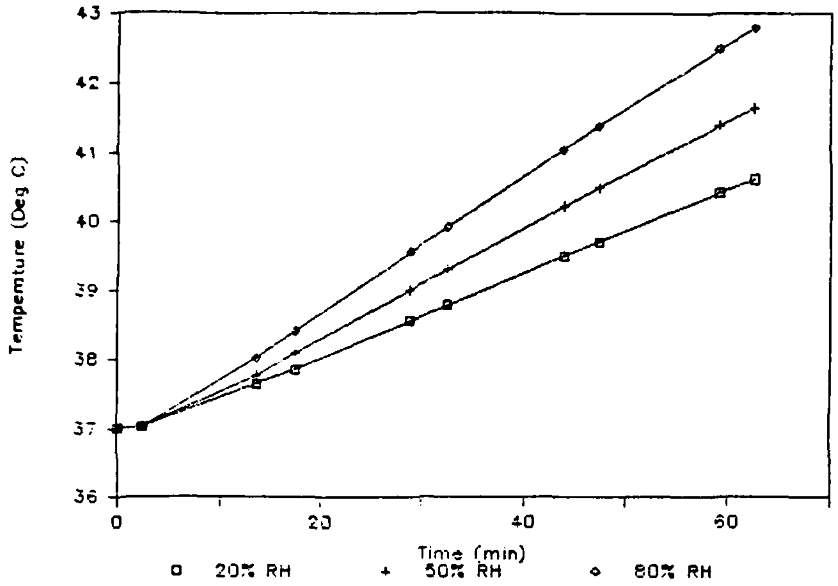

Figure 4-23: T_{ar} vs. Time. Heavy Continuous Work, 38°C

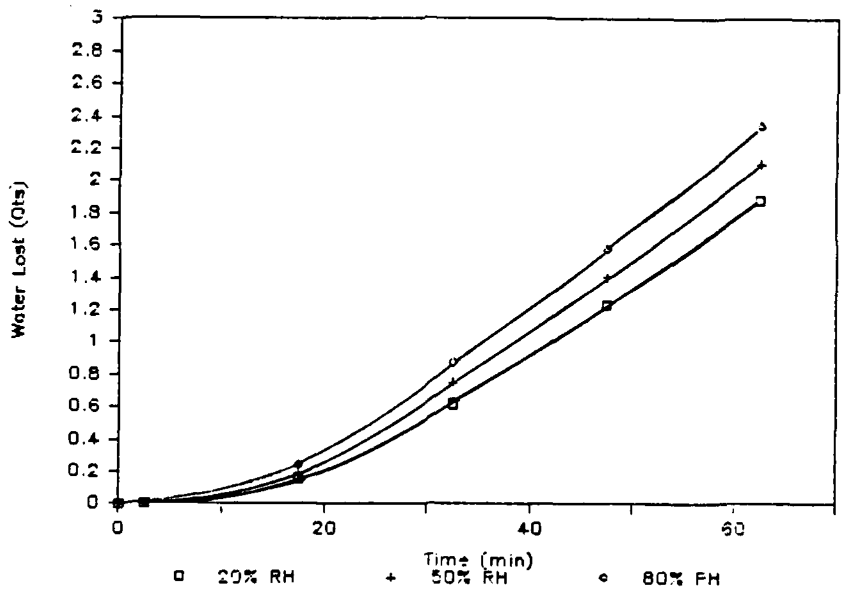

Figure 4-24: Water Lost vs. Time. Heavy Continuous Work, 38°C

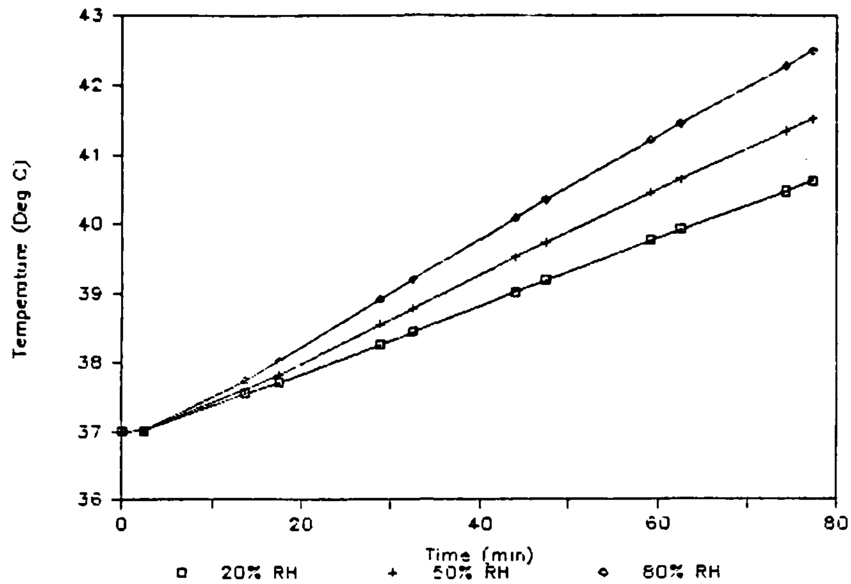

Figure 4-21: T_{ar} vs. Time. Heavy Continuous Work, 33°C

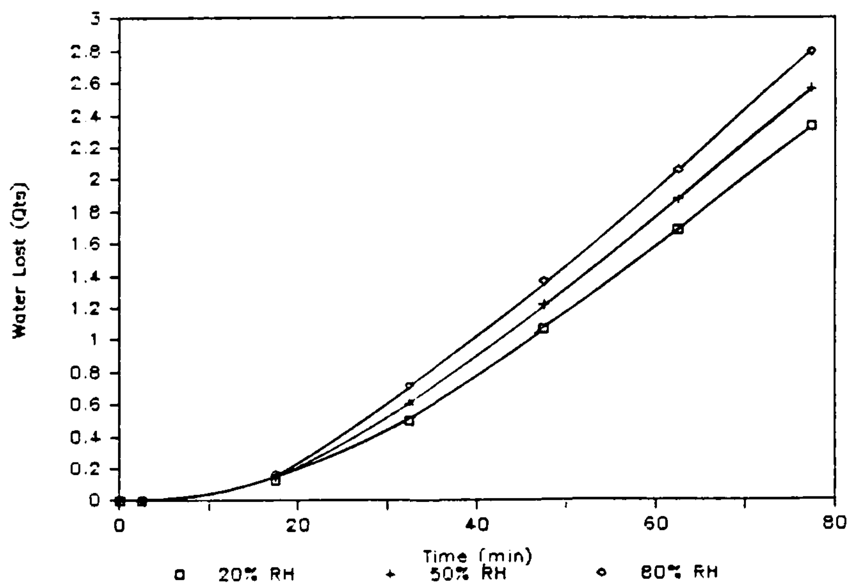

Figure 4-22: Water Lost vs. Time. Heavy Continuous Work, 33°C

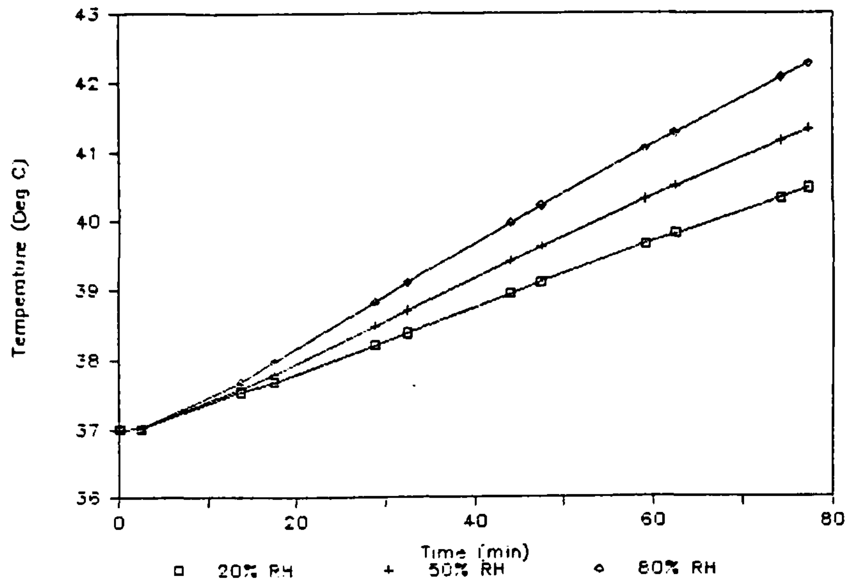

Figure 4-19: T_{ar} vs. Time. Heavy Continuous Work, 32°C

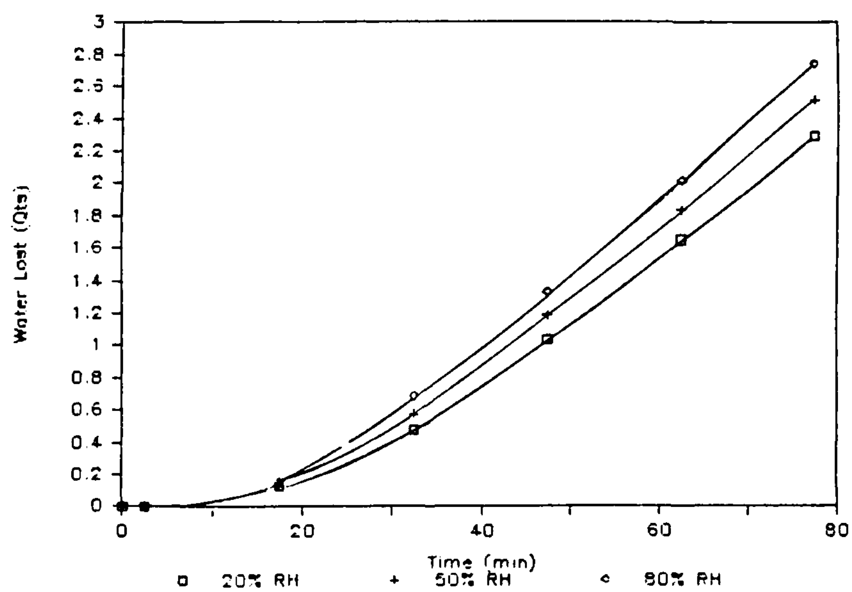

Figure 4-20: Water Lost vs. Time. Heavy Continuous Work, 32°C

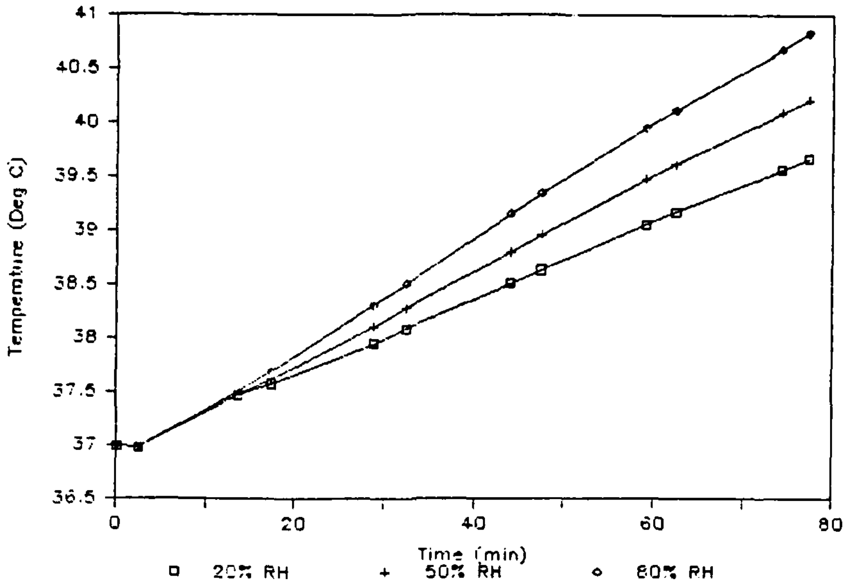

Figure 4-17: T_{ar} vs. Time. Heavy Continuous Work, 26°C

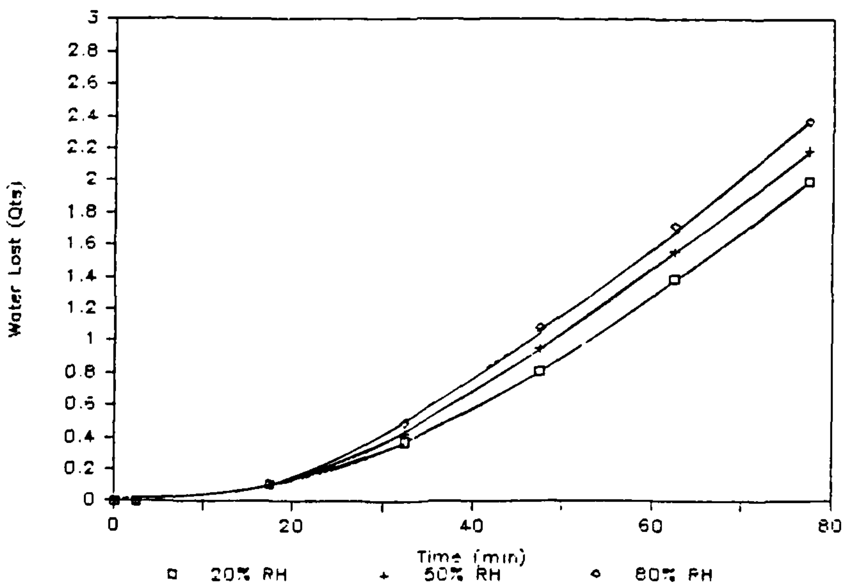

Figure 4-18: Water Lost vs. Time. Heavy Continuous Work, 26°C

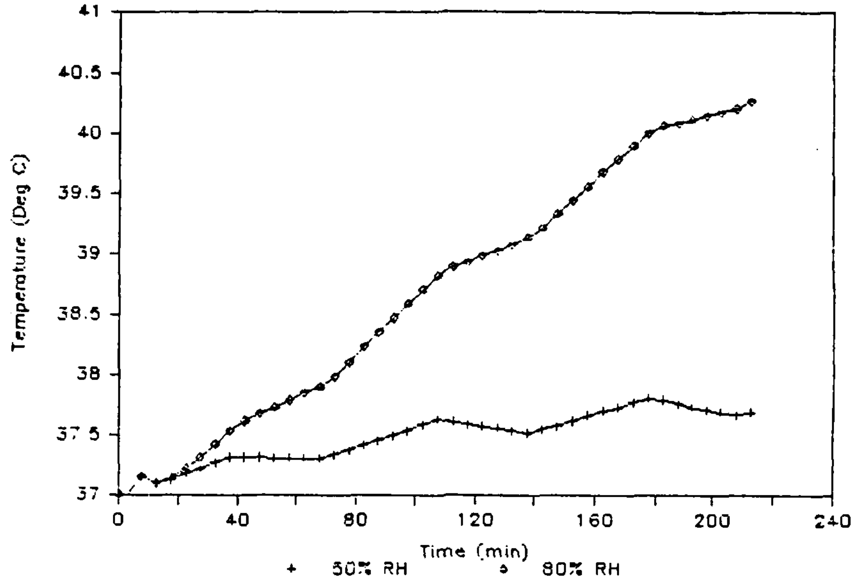

Figure 4-28: T_{ar} vs. Time. Low Work, 33°C, [40-30 Cycle]

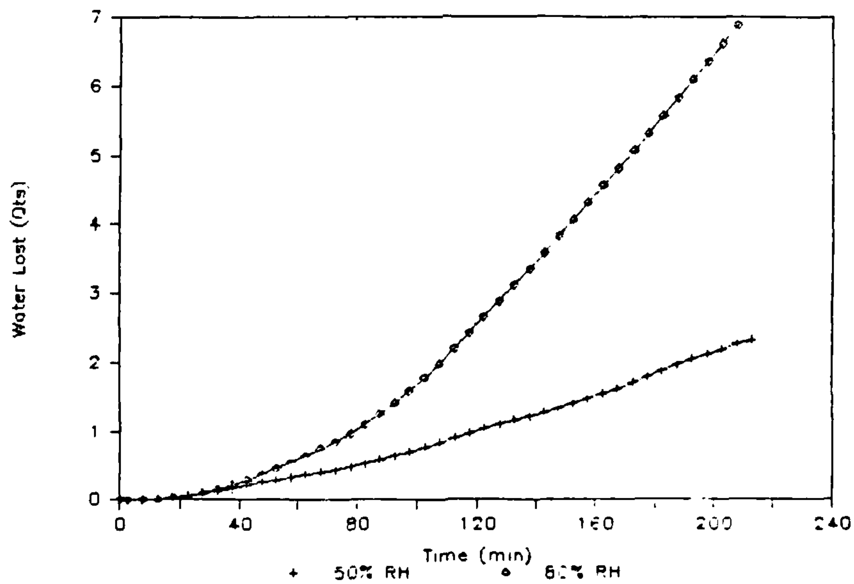

Figure 4-29: Water Lost vs. Time. Low Work, 33°C, [40-30 Cycle]

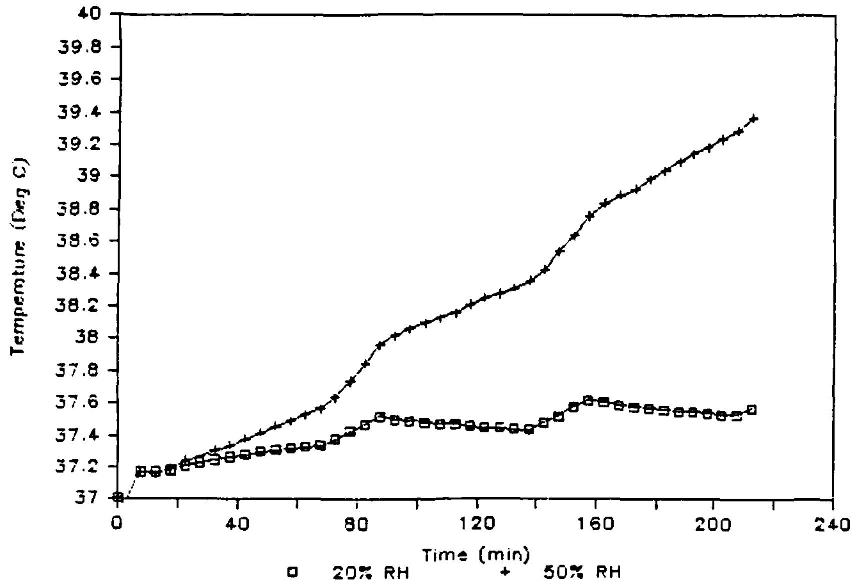

Figure 4-30: T_{ar} vs. Time. Low Work, 38°C, [20-50 Cycle]

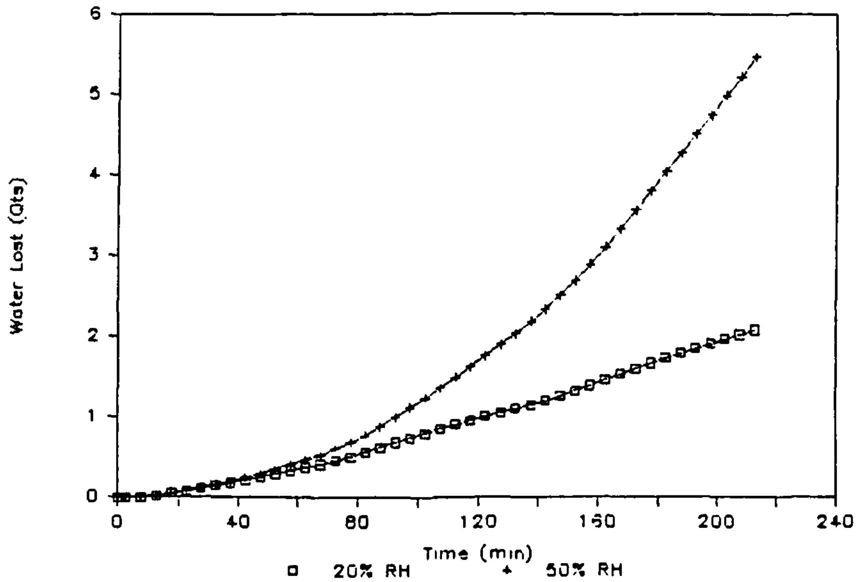

Figure 4-31: Water Lost vs. Time. Low Work, 38°C, [20-50 Cycle]

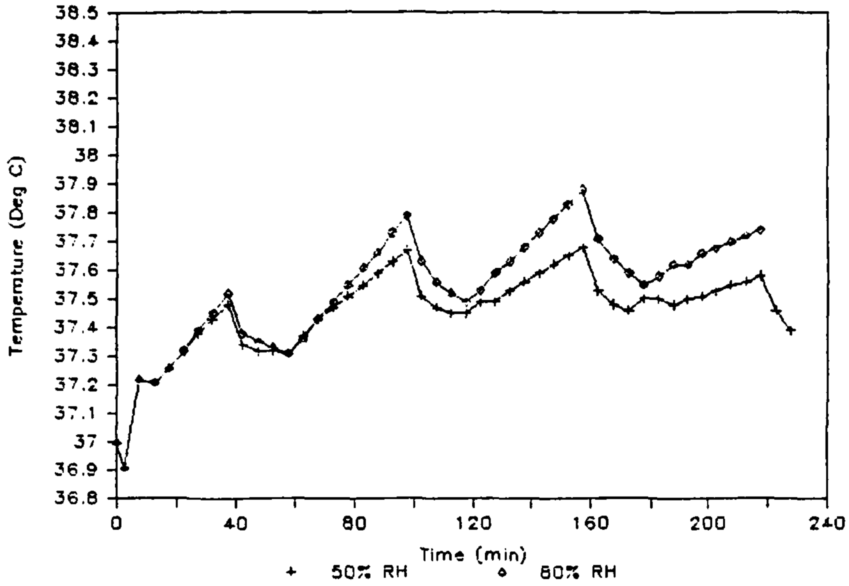

Figure 4-32: T_{ar} vs. Time. Moderate Work, 21°C, [40-20 Cycle]

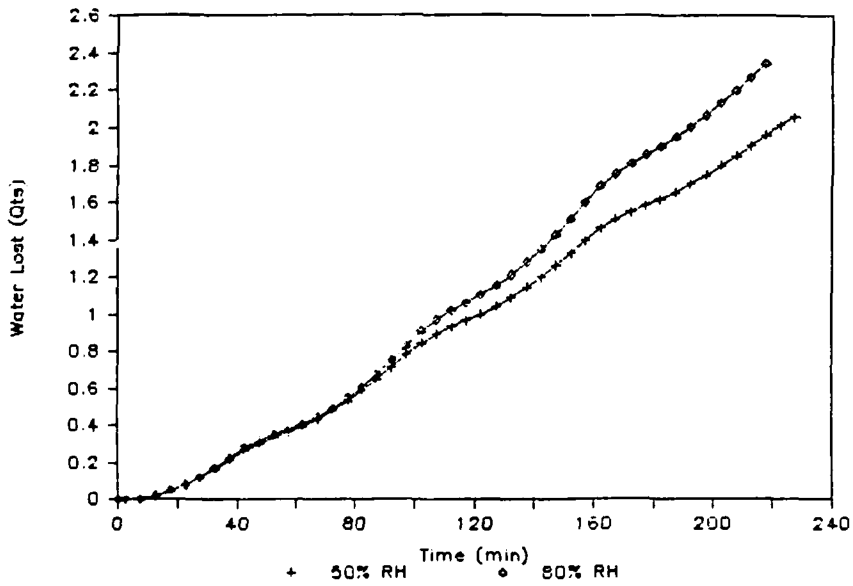

Figure 4-33: Water Lost vs. Time. Moderate Work, 21°C, [40-20 Cycle]

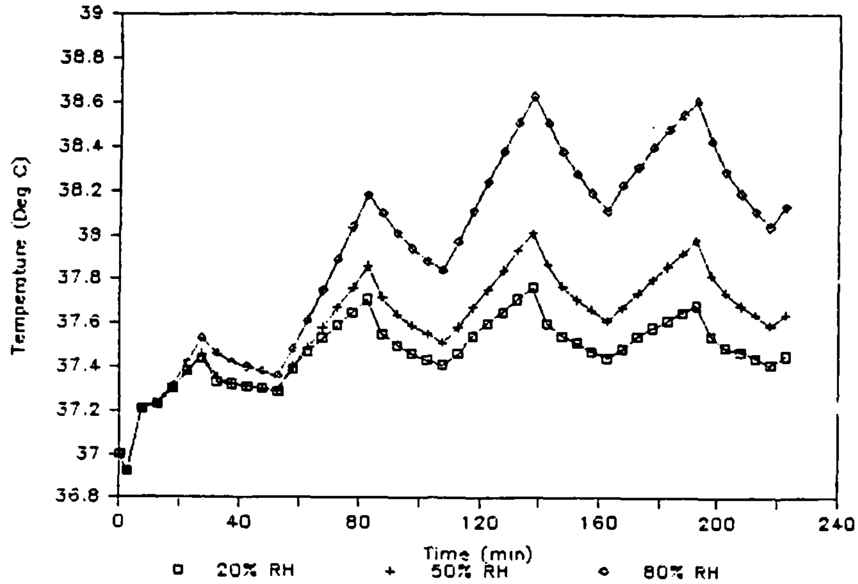

Figure 4-34: T_{ar} vs. Time. Moderate Work, 26°C, [30-25 Cycle]

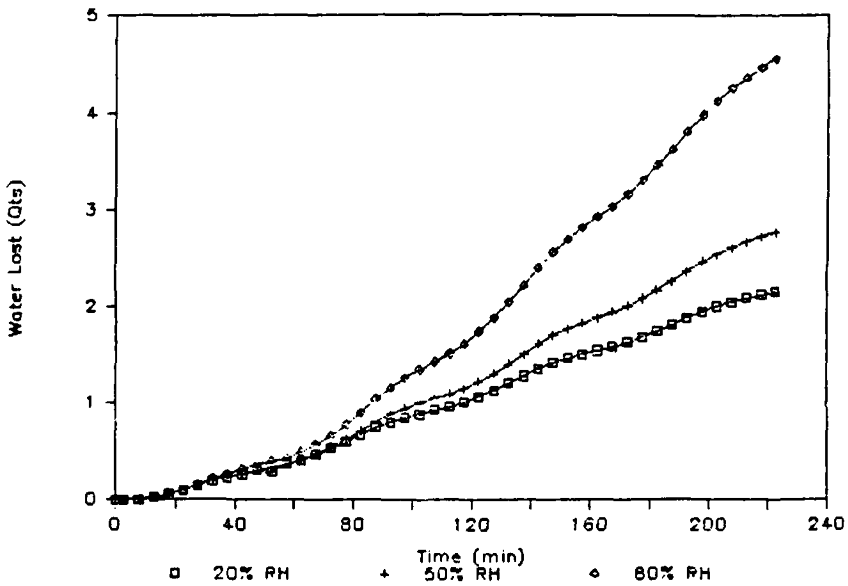

Figure 4-35: Water Lost vs. Time. Moderate Work, 26°C, [30-25 Cycle]

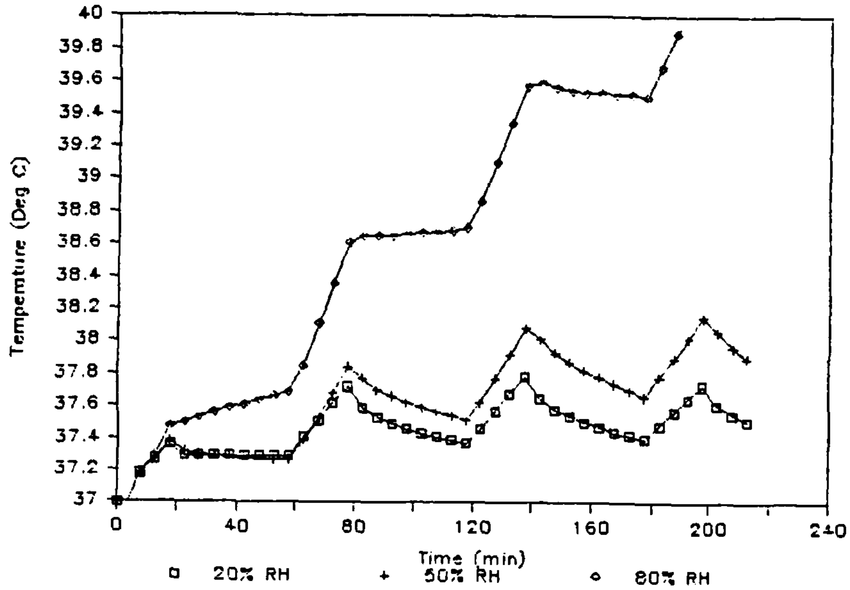

Figure 4-36: T_{ar} vs. Time. Moderate Work, 32°C, [20-40 Cycle]

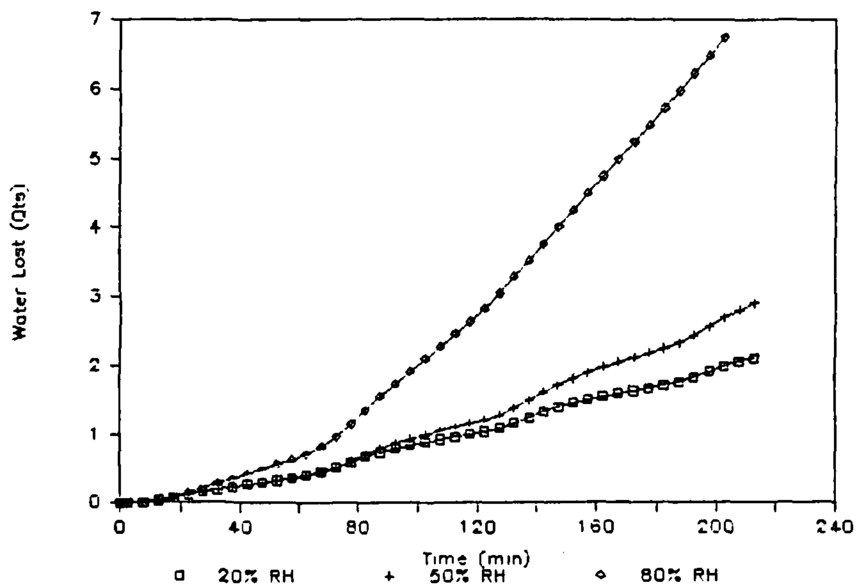

Figure 4-37: Water Lost vs. Time. Moderate Work, 32°C, [20-40 Cycle]

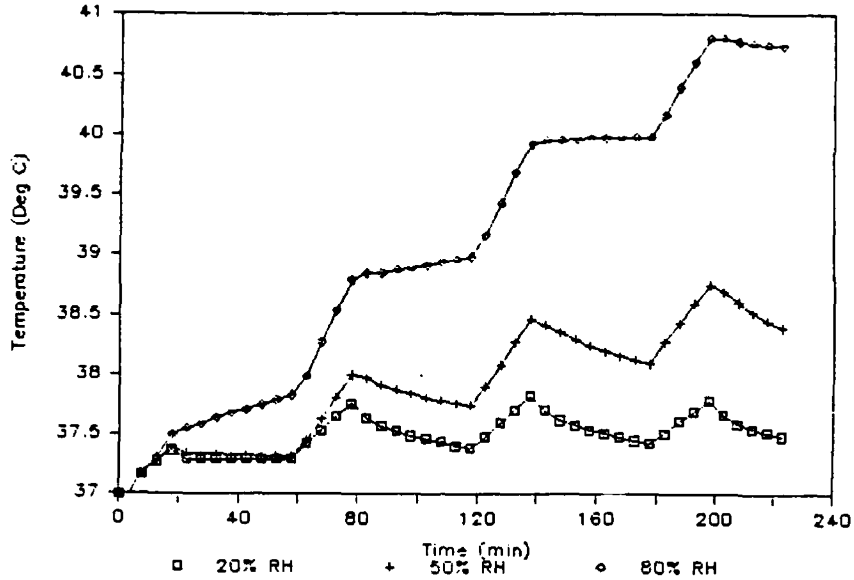

Figure 4-38: T_{ar} vs. Time. Moderate Work, 33°C, [20-40 Cycle]

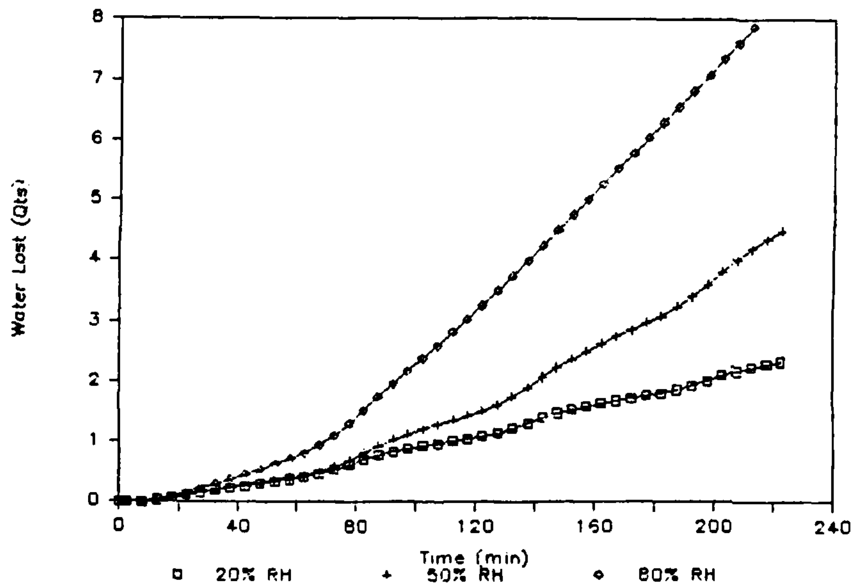

Figure 4-39: Water Lost vs. Time. Moderate Work, 33°C, [20-40 Cycle]

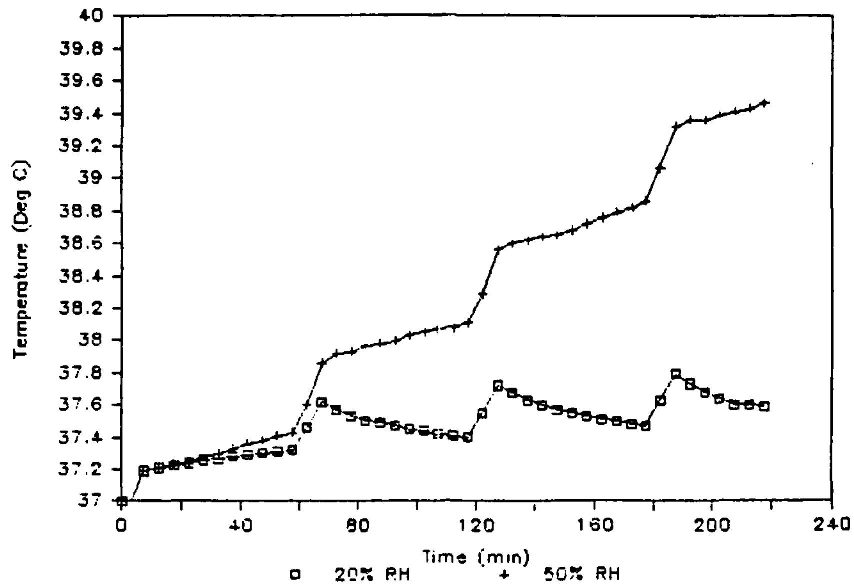

Figure 4-40: T_{ar} vs. Time. Moderate Work, 38°C, [10-50 Cycle]

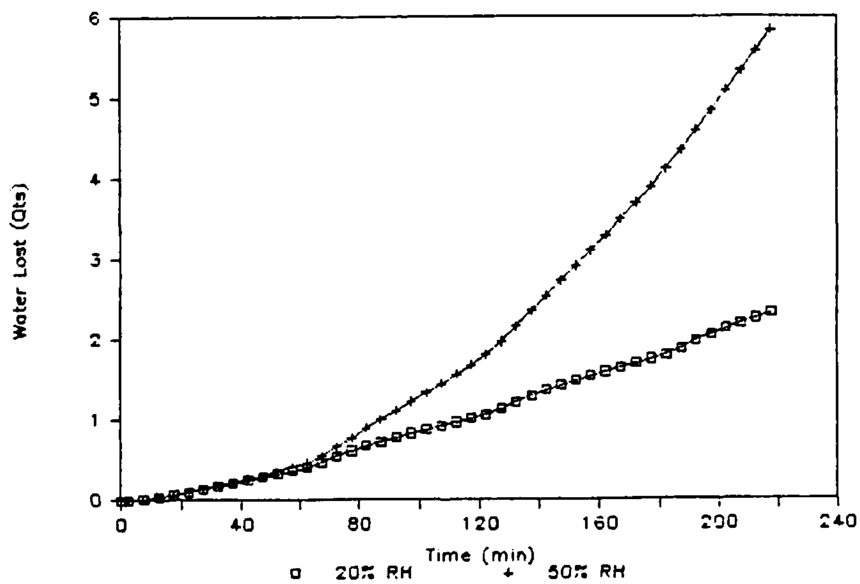

Figure 4-41: Water Lost vs. Time. Moderate Work, 38°C, [10-50 Cycle]

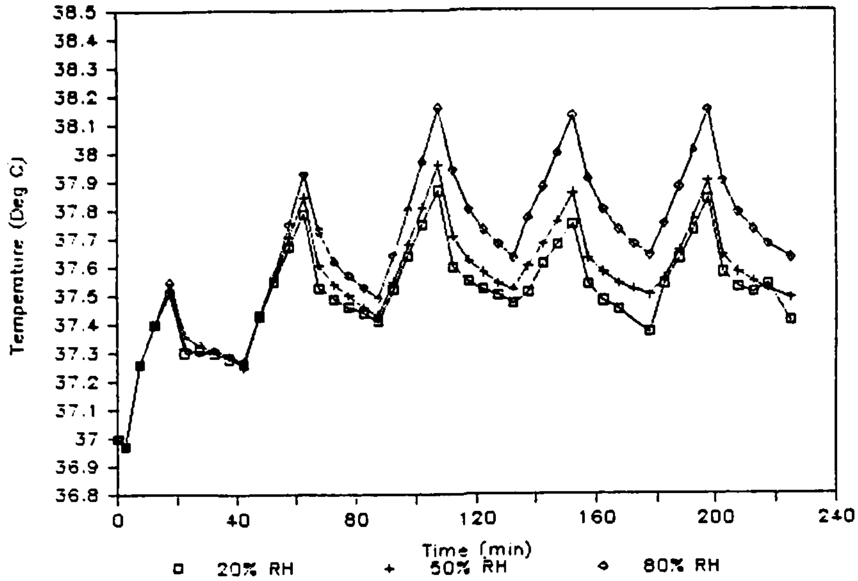

Figure 4-42: T_{ar} vs. Time. Heavy Work, 21°C, [20-25 Cycle]

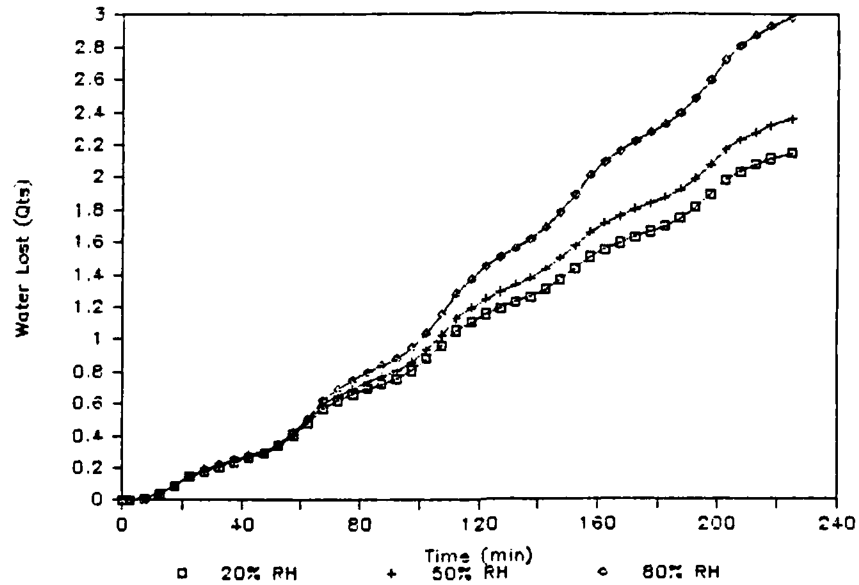

Figure 4-43: Water Lost vs. Time. Heavy Work, 21°C, [20-25 Cycle]

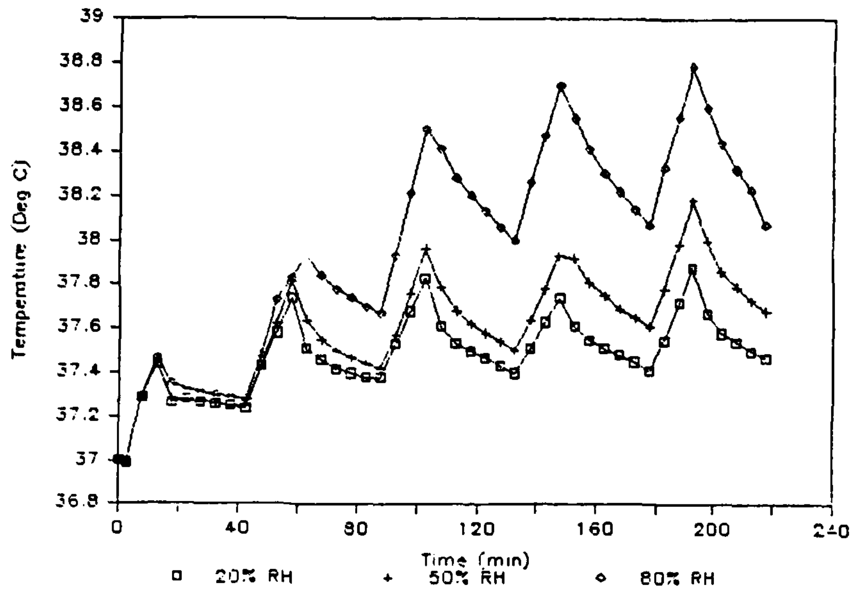

Figure 4-44: T_{ar} vs. Time. Heavy Work, 26°C, [15-30 Cycle]

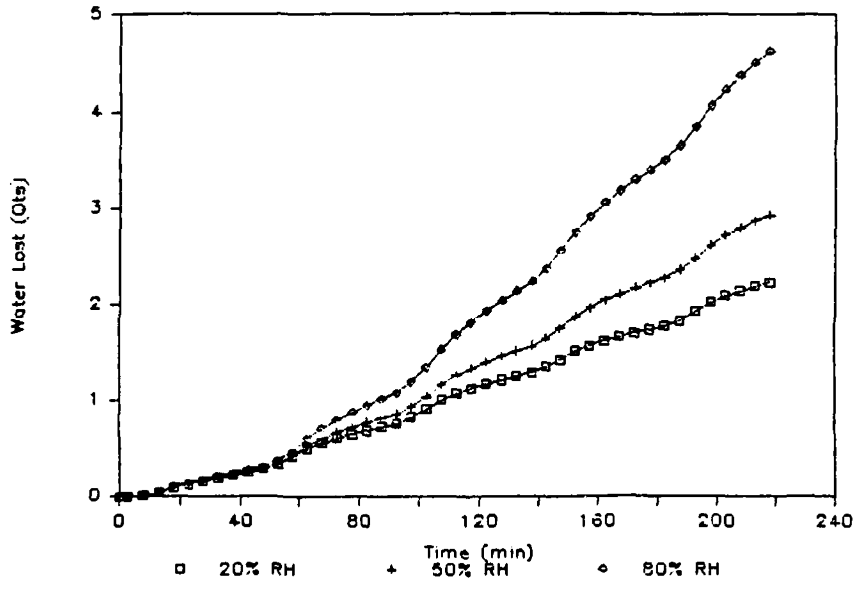

Figure 4-45: Water Lost vs. Time. Heavy Work, 26°C, [15-30 Cycle]

4.2.2 Comparison of Model Results to Basis

Comparison of the computed results of the model in Section 4.2.1 with the values given in Figure 4-27, Section 4.2, and Table 5-2 of FM 21-40, on page 67, shows some interesting results. For the work/rest cycles given, all runs except one (low work, 38°C, 20-50 cycle: see Figure 4-30, Section 4.2.1, on page 70) yield arterial temperatures which do not exceed 38°C when the relative humidity is 50% or lower. For the exceptional case, however, the arterial temperature continues to rise, reaching 39°C at 175 minutes. Even in this case, the arterial temperature safety limit is reached after the water loss safety limit (3 quarts of water were lost in 160 minutes). Thus, the cyclic work/rest ratios given in Table 5-2 of FM 21-40 seem to be good ratios for controlling the arterial temperature when the relative humidity is 50% or less.

When the relative humidity is raised to 80%, the usefulness of the suggested work/rest cycles presented in Figure 4-27, Section 4.2, and Table 5-2 of FM 21-40 becomes questionable. In three of the six cases, the computed arterial temperature exceeds 39°C; see Figures 4-28, 4-30, and 4-36, Section 4.2.1. Of the remaining three cases, one stabilizes at 38.65°C; see Figure 4-34, Section 4.2.1. These results seem to indicate that the cycle times given in Figure 4-27, Section 4.2, and Table 5-2 of FM 21-40 are useful at moderate temperature levels, but are not useful at high temperatures and low work levels when the relative humidity is high.

A comparison of the time to reach the arterial safety limit (39^oC) and the time required to reach the safety limit for water loss (3 quarts), is presented in Tables 4-2 and 4-3, respectively, on pages 79 and 81. Table 4-2 shows the times for those environmental cases in which the arterial temperature is not stabilized by the work/rest cycle used. It is interesting to note that of the five cases listed, the time required to reach the water loss limit is lower than the time to reach the arterial temperature limit in three cases, and higher in the other two. All five cases in which safety limits are reached occur at low or moderate work levels, high environmental temperatures, and the relative humidity at or above 50%. The difference in times to reach the two safety limits for each case is small enough that either limit could be used. This suggests that work/rest cycles are more effective in controlling the elevation of arterial temperature than limiting the amount of water lost. This is confirmed by the fact that for all five of these cases, the limiting factor under continuous work was the elevated arterial temperature.

Table 4-2: Water Loss vs. Arterial Temperature Limiting Times

Work Level	Temperature (C)	Relative Humidity	Time to Reach Safety Limit (min) Water Loss	Arterial Temperature
Low	33	80%	130	125
	38	50%	160	175
Moderate	32	80%	128	125
	33	80%	118	119
	38	50%	155	180

Table 4-3 lists the time to reach the safety limit for water loss for all cases where the arterial temperature stabilizes below 39°C. For those values marked as estimates, the estimate is generous: the actual time to reach the safety limit should be less than the value listed. In spite of this, there is no case in which the limiting time is as long as six hours. This is a significant point because the United States Army expects that it will be required to fight in an NBC environment for as long as six hours without relief [2, 7, 41]. For most of the environmental conditions which were simulated, a safety limit is reached within five hours (300 minutes), implying that most soldiers will dehydrate before they can be relieved and decontaminated, if no additional water is made available. This suggests that the commanders of units that are placed in an NBC environment must take steps to insure that additional uncontaminated water is made available to the troops as soon as possible.

Table 4-3: Water Loss Limiting Cases for Cyclic Work/Rest Times

Work Level	Temperature (C)	Relative Humidity	Time to Reach Safety Limit (min) Water Loss	Arterial Temperature
Low	33	50%	262 (est)	Stabilized
	38	20%	293 (est)	Stabilized
Moderate	21	50%	320 (est)	Stabilized
		80%	264 (est)	Stabilized
	26	20%	340 (est)	Stabilized
		50%	248 (est)	Stabilized
		80%	163	Stabilized
	32	20%	304 (est)	Stabilized
		50%	216	Stabilized
	38	20%	276 (est)	Stabilized
Heavy	21	20%	316 (est)	Stabilized
		50%	282 (est)	Stabilized
		80%	220	Stabilized
	26	20%	288 (est)	Stabilized
		50%	218	Stabilized
		80%	162	260 (est)

NOTE: (est) = Estimated time. Extrapolated from graph.

Chapter 5

Summary and Conclusions

5.1 Summary

The United States Army faces a critical problem in trying to prevent heat casualties among soldiers who wear MOPP equipment during warm weather. This problem is compounded for those who will not receive LCV's in the near-term future. Therefore, an effort must be made to accurately predict maximum performance times and establish safety limits for soldiers in all levels of MOPP.

This report has used a computer model for human thermoregulation developed by Dr. Wissler, from the University of Texas at Austin. An evaluation has been made of currently published guidelines for the Army, which are in FM 21-40, Tables 5-2 and 5-4. Guidelines for the continuous work were found to be inadequate due to the omission of the effect of humidity. Humidity was found to have a significant impact in low work - high temperature situations. Water loss from the body was also calculated and found to be a limiting factor at moderate temperatures, and at high temperatures where only low level work is done (refer to Section 4.1.2).

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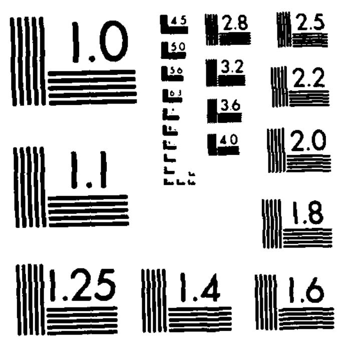

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The cyclic work/rest values in Table 5-2 of FM 21-40 were found to provide adequate guidance for regulating the elevation of arterial temperature at all temperatures when the relative humidity is below 50%. The suggested work/rest times were only marginally safe at high humidities with high temperatures. When the arterial temperature does not stabilize, the time required to reach the arterial safety limit is close to the time required to reach the water loss safety limit. When the arterial temperature stabilizes, loss of water becomes the limiting factor. Furthermore, for none of the work/rest cycles given in Table 5-2 of FM 21-40, nor for the two additional cases tested, can one expect neither safety limit to be violated for a six hour period (refer to Section 4.2.2).

A standard has been suggested for use in defining the meaning of 'marginal' and 'negligible' casualties. Safety limits are recommended for both both elevation of arterial temperature and for bodily water loss (see Section 2.3). It is recommended that Table 5-4 of FM 21-40 be modified to incorporate humidity into the parameters which define continuous work safety limits. This results in the presentation of an effective temperature graph that can replace Table 5-4 (refer to Figure 4-26, Section 4.1.3, on page 64).

5.2 Recommendations for Future Work

This report has merely touched on the problem of predicting thermal stress for soldiers in MOPP. A complete review of Tables 5-2 and 5-4 from FM 21-40 needs to be done. These tables need to be updated so that they agree with the current MOPP levels. Likewise, it is recommended that an effective temperature graph for continuous work be incorporated into FM 3-4 in order to provide guidelines for safety limits and also make allowance for humidity effects.

Since the number of cyclical work/rest combinations is enormous, an extensive study needs to be conducted in order to find the optimum work/rest cycle times for different environmental cases. This study should look at the possibility of developing an effective temperature graph, similar to the one presented in this report, for replacement of Table 5-2 from FM 21-40. This graph should then be incorporated into FM 3-4 to supplement the degradation times listed in Appendix A of FM 3-4.

Water loss from the body, and its significance to the safety of soldiers, was barely touched in this report. Because of its apparent significance, especially if work/rest cycles are used, a study should be conducted in order to determine the full effect of water loss. If possible, the effect of water loss should be incorporated into the tables or the graphs used to provide guidelines. This could simplify the commander's job by providing one table or graph, instead of two, whicn define the limits of tolerable performance.

Currently only Brigade level medical units have the equipment necessary to determine a Wet-Bulb Globe Temperature. Work has been done to provide a simple piece of equipment, that will allow commanders at the company/battery/troop level to determine a WBGT in order to determine the appropriate safety limits [42]. This piece of equipment, known as the BOTSBALL thermometer, consists of a hollow copper sphere that is painted black and covered with black cloth. The cloth covering is continuously moistened by water seeping from the reservoir tube attached to the globe. The stem of a dial thermometer passes through the reservoir tube and into the copper globe. The dial of the thermometer is color coded for different temperature ranges [43]. A picture of the BOTSBALL thermometer is shown in Figure 5-1, on page 86. The one drawback of the BOTSBALL thermometer is that the single reading must be converted to a WBGT reading. Future work should include development of an effective temperature graph using the BOTSBALL thermometer.

Wissler's model appears to predict accurately tolerance times based on arterial temperatures. Its ability to predict water loss from the body has not been established. Therefore, a study should be conducted to validate Wissler's model for water loss from the body. If this can be done, this model will provide a powerful tool for estimating thermal stress under a variety of conditions.

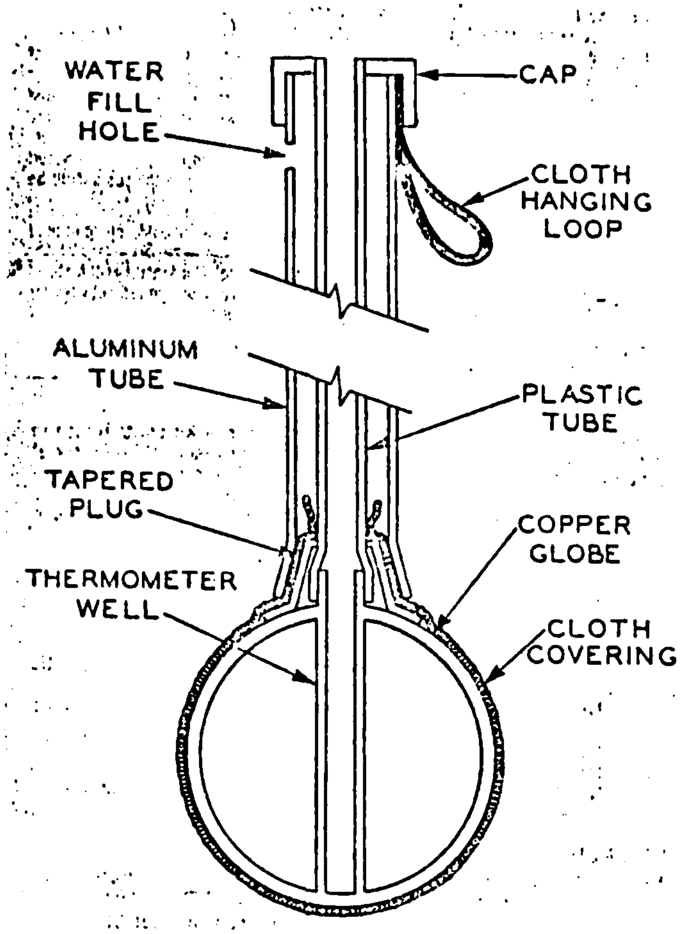


Figure 5-1: BOTSBALL Thermometer [43]

5.3 Conclusions

The following conclusions may be made from the information presented in this report:

1. The current guidelines for the safety of Army personnel while wearing MOPP equipment are inadequate and out-of-date. These guidelines need to be updated in order to reflect current doctrine and to provide better safety guidelines.

2. Wissler's thermoregulatory computer model adequately predicts thermal stress for soldiers who are in a MOPP-IV posture. Wissler's model may be used to predict tolerance times based on arterial temperatures. Further studies need to be conducted in order to establish the validity of this model for water loss.

3. Humidity has a significant effect on tolerance times for personnel in MOPP-IV. Humidity needs to be included in any safety guidelines. The WBGT provides a simple way to incorporate the effect of humidity into the guidelines.

4. Water loss from the body may be the limiting factor at moderate temperatures and at high temperatures when low level work is performed.

NOTE: Several important references were received after this report had been completed. In order to update the report in the shortest amount of time, the references are evaluated in Appendix B.

Appendix A.

Soviet Tactical Doctrine and the US Response

A.1 Introduction

This appendix is designed for the reader who has little or no knowledge of Soviet military doctrine. It is felt that in order to appreciate the remarks made in Chapter One of this report, the reader should understand the threat. This appendix will give only a quick overview of the Soviet threat doctrine and the current US response to that doctrine. The information provided here is taken from unclassified sources [44, 45, 46, 47, 48, 49]

A.2 Soviet Doctrine

The Soviet philosophy for offensive warfare is to attack in echelons. The use of echelons has been in the Soviet doctrine since the 1930's, when the concept of "Deep Operation" first appeared. This concept was developed in order to counter the positional warfare that dominated the First World War. In essence, "Deep Operation" combines breakthroughs of the enemy defenses with rapid exploitation of those

breakthroughs. The exploitation is achieved by the follow-on echelons which are pushed through the breakthrough point as quickly as possible.

Echeloning is a force structuring device that divides an army in depth on a narrow frontage in order to achieve a rapid and irresistible buildup of pressure on a small sector of the defense. Echelons differ from reserves (which the US Army uses) in that echelons are given their orders before the start of the battle. This way they can be committed quickly, thus achieving the overwhelming buildup necessary for success. The first echelon engages the enemy and finds any weak spots in the defense. It then attempts to break through the weak spots. As the first echelon loses momentum, the second echelon literally passes through the first and continues the attack. It is through this "passing" that the momentum of the attack is maintained, and the Soviets feel this will insure a breakthrough.

A critical part of the breakthrough is not just the speed with which it occurs, but also the protection from counterattack that it provides for the units which are pushing through. Soviet doctrine calls for use of persistent chemical agents on the flanks, if the situation is critical, to deny the enemy any avenues for counterattack. The use of persistent agents would require NATO forces to cross a contaminated area in order to counterattack. This would effectively slow the counterattacking forces, and also reduce their effectiveness since they would have to fight in protective clothing.

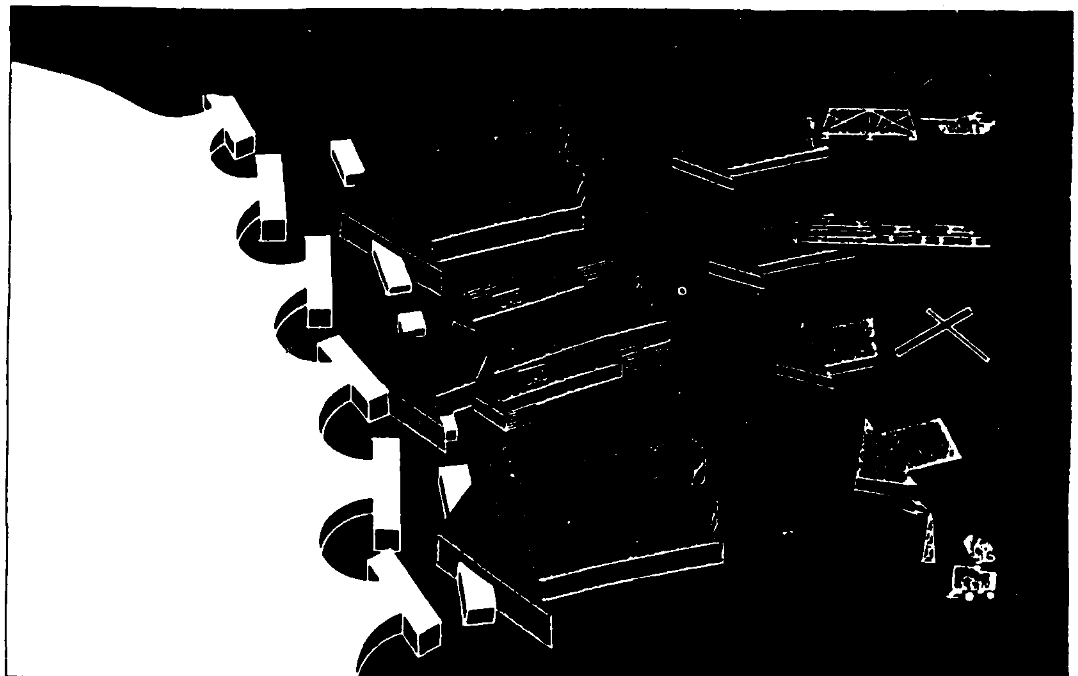
During the exploitation phase, the Soviets feel that a rate of advance of 3 to 45 kilometers per day is needed to remain on the offense. The actual rate would depend on the terrain, weather, enemy strength, and use of nuclear/chemical weapons. The faster the rate of advance, the shorter the time required to achieve their objectives. The Soviets believe that a rate of advance of 15 kilometers per hour (KPH) will negate the use of tactical nuclear weapons due to the time delay between target aquisition and the actual time of the weapon hitting the target. This condition also exsists for use of chemical weapons.

A.3 Change in Soviet Doctrine

During the 1960's and for most of the 1970's, the Soviets felt that a two echelon force offered the greatest threat to the NATO defense. This structure, it was felt, effectively countered the NATO strategy of early use of tactical nuclear weapons. However, during the 1970's, it became clear to the Soviets that NATO might not use nuclear weapons, except as a last resort. Thus, the Soviets changed their thinking from protecting their forces from nuclear attack to achieving rapid gains and intermingling with NATO forces as quickly as possible to preclude NATO's use of nuclear weapons.

Since NATO forces deploy well forward in the General Defense Plan (GDP), the Soviets will meet the bulk of the NATO forces almost immediately after crossing the international border. This will require

the Soviets to penetrate the NATO defense quickly in order to intermingle with NATO units. This requirement has led to revision of the Operation Manuever Groups (OMG). By using OMG's, the Soviets can mass most of their strength in the first echelon, in a small area, and hopefully achieve a rapid breakthrough. The OMG's, which can operate independently for a short period of time, are then sent on raids into the NATO rear area to take out command posts, nuclear weapon sites, and other areas vital to the use of nuclear and chemical weapons. The Soviets hope to be able to reduce NATO's forces to fighting a conventional battle. See Figure A-1 below.



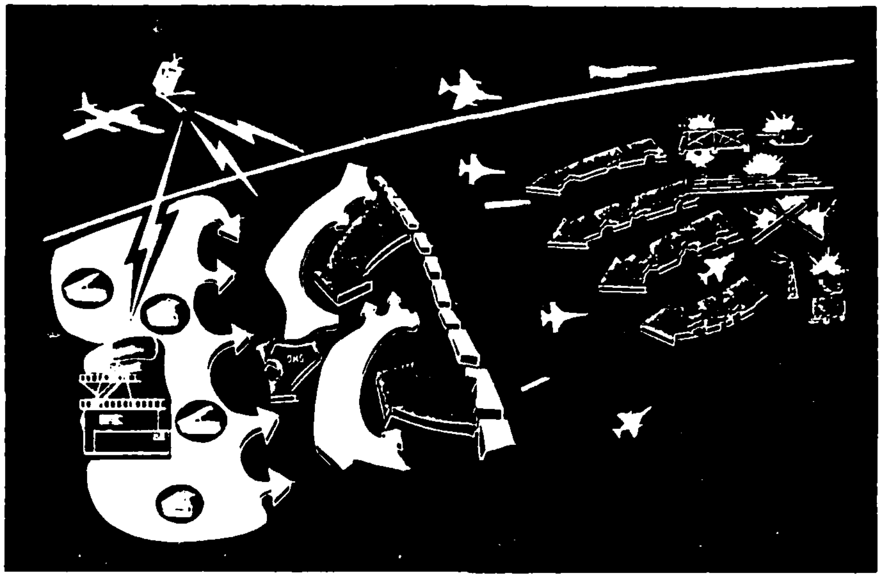
The enemy's leading forces are shown as having crossed the border and attacking NATO's General Defensive Position (GDP). Note the enemy's follow-on forces to the rear of his leading elements. These follow-on forces are poised to reinforce or to exploit whatever successes his leading elements may achieve.

Figure A-1: Soviet Attack on NATO [42]

A.4 NATO Response

The Allied Command, Europe (ACE) has developed a doctrine to combat the Soviet "Deep Operation." This doctrine is known as Follow-on Forces Attack (FOFA), and is very similar to the US Army doctrine of Air/Land Battle. The strategy of FOFA is to interdict as many forces as possible behind the front units of the first echelon in order to prevent the Soviets from achieving overwhelming odds. In essence, this would force the Soviets to attack piecemeal, and the NATO forces could then defeat the enemy in detail. This strategy against the changing Soviet doctrine is still current since the OMG's are actually the second echelon of the first echelon. Therefore, they would be behind the front units, thus falling into the FOFA list of units to interdict.

If any Soviet breakthroughs do occur, the NATO reserves would counterattack to restore the front line of friendly troops (FLOT), thereby denying the Soviets the ability to exploit the breakthrough or intermingle with NATO units. If needed, the NATO FLOT would be realigned on the next defensible positions in order to re-establish the FLOT. See Figures A-2 and A-3.



At the General Defensive Position, the enemy is beginning to make inroads but is suffering considerable losses in the process. Using stand-off target acquisition systems, NATO has identified the enemy's follow-on forces. These follow-on forces are then engaged using aircraft and indirect fire weapons. This FOFA operation is conducted concurrently with the battle at the GDP.

Figure A-2: Follow-on Forces Attack Doctrine [42]

The situation at the GDP has been restored and the enemy is obliged to try to bring forward additional troops if he wishes to attack again. These troops moving forward would, of course, also be vulnerable to follow-on forces attack.

Figure A-3: Restoration of the Front Lines [42]

A.5 Evaluation of the Opposing Doctrines

The Soviets are determined to use all means available to remain on the attack. They view breakthrough and exploitation as fundamental to their war effort. The NATO forces feel that the Soviets must be stopped as quickly as possible since any ground given up, if not regained, will remain under Soviet influence. This implies that any breakthrough will be met by counterattack, and that the Soviets will have to mass most of its forces early in order to achieve a breakthrough. In short, the Soviets may be forced to use non-persistent agents in order to achieve a breakthrough, and then use persistent agents to slow down the NATO counterattack. Thus, the possibility of chemical agents being employed is enhanced by the two doctrines currently held by the Soviets and NATO.

Appendix B.

Evaluation of New References

B.1 Introduction

Several important documents were received only days before the final submission of this report. Due to the lack of time, these documents were not able to be incorporated into the main report. However, because of their subject matter, it was felt that a brief evaluation of the documents was warranted. This appendix will evaluate these documents and briefly outline the major themes and their impact on the findings of this report.

B.2 Determination of Metabolic Rates

In Section 3.3.1 the metabolic rates for low, moderate, and heavy work loads were determined to be 200, 350, and 500 Watts, respectively. As previously discussed, these values were arrived at by comparing the examples given in FM 21-40 to a published table of energy expenditures for different activities. None of these activities, however, were of a military nature. A study conducted by Goldman and

Joy [50] contains a detailed list of military tasks and their associated metabolic rates. These values were derived from experimental data collected in field exercises. Comparison of this table with the rates chosen indicates that the initial values were correct. The 200 Watt level corresponds to the energy expended by a mine sweeper operater (203 W). The 350 Watt level is close to the energy expended by an M-60 machine gunner on patrol (351 W). And the 500 Watt level corresponds to an Infantryman in a fire fight in a jungle (509 W). Comparison of the examples listed in FM 21-40 to the study shows that no administrative or motorized movements are tabulated. For the moderate level example of improvement of a rear area position, the associated metabolic rate is 284 Watts. The heavy work example (dismounted Infantry assault) has an associated metabolic rate of 483 Watts. Thus the values chosen are in close aggrement with experiementally determined metabolic rates. It should be noted here that values given in TB MED 507 [51] differ. The values given for light, moderate, and heavy work are 177, 223, and 270 Watts, respectively.

B.3 Determination of Work/Rest Cycles

Current published Army guidelines for the establishment of work/rest cycles is conflicting, and at the best confusing. The manual on occupational and environmental health, TB MED 507, uses the WBGT, but makes no mention of any work/rest cycles [51]. A more recent circular [52], DA Circular 40-82-3, recommends the use of the Wet Globe

Temperature (WGT) from the BOTSBALL thermometer, with 5.5°C (10°F) being added to the temperature read. Then, based on the WGT only, there are four work/rest cycles given. These cycles are not affected by the type of work being performed. The cyclic values given in FM 21-40, as previously discussed, use a dry bulb temperature and type of work to determine the appropriate work/rest cycle. Two more recent letters [53, 54] give work/rest cycles based on type of work, MOPP level, and WBGT. However, upon examination of the charts in the letters, it was found that the values in both charts are exactly the same, but the MOPP levels listed are different. Thus, it is hard to determine just which system the Army units should use.

The most recent values listed [53] seem very conservative since for MOPP IV, no work/rest cycle is given for a WBGT above 23.9°C (75°F). Both FM 21-40, and this report feel that higher temperatures can be tolerated with appropriate work/rest cycles. It is recommended that a definitive standard be published as soon as possible and all other methods be superceded in order to reduce confusion.

B.4 Determination of Water Intake

The same disparity that exists for work/rest cycles also exists in the level of water intake. FM 3-4 (Draft) recommends one quart of water be consumed every three hours for moderate to heavy work at a temperature below 27°C (80°F). The amount is increased to one quart

every two hours for temperatures above those previously mentioned. TB MED 507 recommends one quart of water be consumed every 2.67 to 3.43 hours for a WBGT below 27°C, and when the temperature is above 27°C, one quart should be drunk every 1.85 to 2.67 hours [51]. DA Circular 40-82-3 [52] gives no amount for a BOTSBALL temperature below 27°C. For temperatures above 27°C, the amount of water that is recommended to be consumed climbs to a maximum of two quarts per hour when the BOTSBALL temperature is at 31.1°C (88°F) or higher.

None of the references try to determine how much water can be lost prior to incapacitation due to dehydration. Since it has been shown that there is a tendancy not to completely replenish the water lost while in MOPP IV, [29] it is recommended that the discussion presented in this report be taken into consideration.

B.5 Determination of Continuous Work Limits

None of the references discuss any safety limits for continuous work while in MOPP IV. This seems to be significant since continuous work at high WBGT temperatures results in the shortest amount of time before the onset of heat related injuries. It is highly recommended that safety guidelines for continuous work be addressed. Since the use of the BOTSBALL thermometer will increase, a preliminary attempt has been made to develop an effective temperature graph for use with the BOTSBALL thermometer. Refer to Figure B-1, on page 100. This graph is

only a preliminary graph. Further work will need to be done to determine the best way to convert the BOTSBALL thermometer reading into a WBGT temperature, since most of the relavant data is measured in terms of WBGT. Two different equations were tried for converting the WGT. The equation used is shown in Figure B-1.

The references cited in this appendix have tried to address many current problem areas with thermal stress for soldiers who are in MOPP IV. However, the references tend to contradict instead of supporting each other. It is recommeded that all effort be made to correct the problems noted in this appendix as soon as possible.

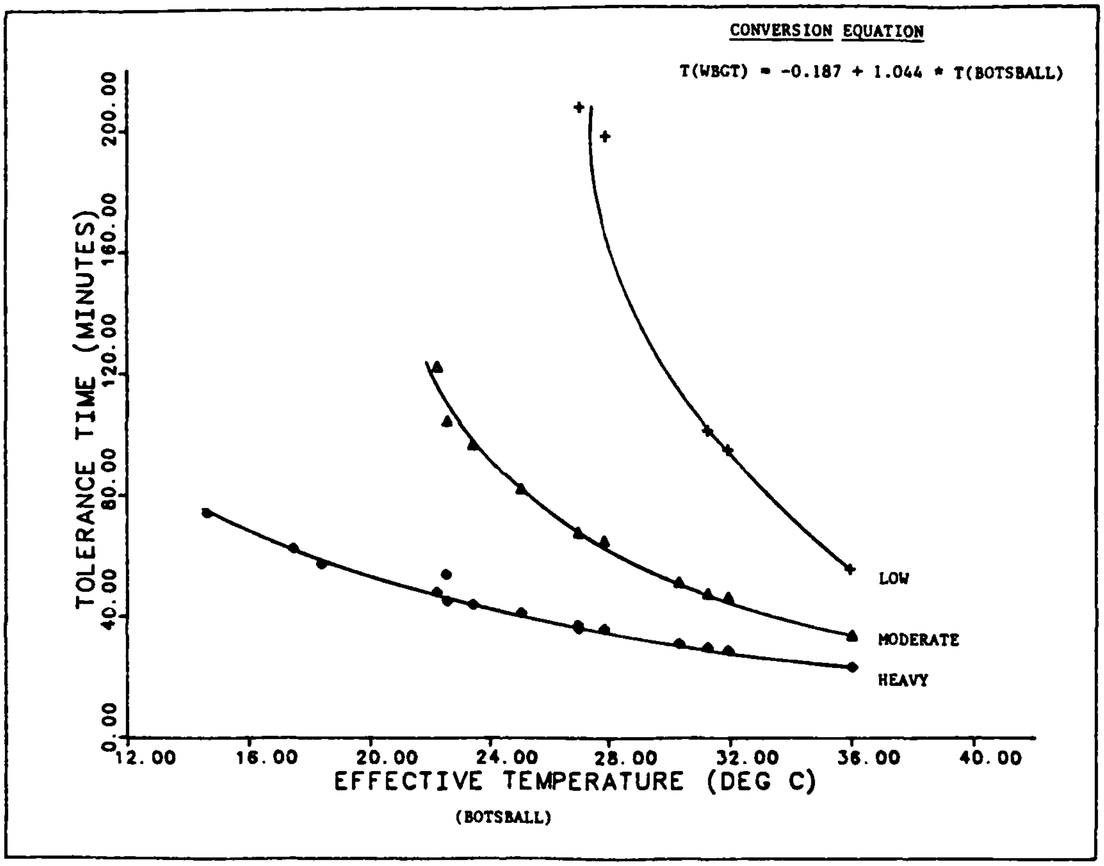


Figure B-1: Tolerance Times vs. $T_{BOTSBALL}$

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